THE PER

COMP

A. T. MACKE

EXECUTIVE ENGIN

Madras:
PRINTED BY THE SUPERINTENDEN

1899.

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HISTORY

OF

THE PERIYÁR PROJECT.

[PRICE, 10 *rupees.*] [15 *shillings.*]

Colonel J. PENNYCUICK, R.E., C.S.I.

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PREFACE.

THE following account of the Periyár Project has been compiled mainly from official reports, supplemented by a long personal employment on the works and by information from brother officers of the Madras Public Works Department similarly engaged. I wish to record my thanks to Mr. W. Hughes, Mr. S. D. Pears, Mr. T. W. Smyth, Mr. H. T. Keeling, and very specially to Mr. S. Krishnama Chariar, without whose assistance an account of the works in the plains must have been very meagre; and also to Mr. J. P. Davidson for his help with the plans.

There is a chapter still to be written upon the agricultural and financial results. From this standpoint the present account is twenty years too early, and must be taken merely as an engineering history of the inception of the project and of the difficulties encountered in its execution.

References to individuals would be out of place, but I have thought right, with the approval of the Madras Government, to introduce as a frontispiece a photograph of the remarkable man to whom both the design and the accomplishment of the project are chiefly due. Colonel John Pennycuick has left in Madras an honoured name, and has bequeathed a heritage of exalted ideals which should never be suffered to decline.

A. T. MACKENZIE.

LONDON,
22*nd April* 1898.

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HISTORY

OF

THE PERIYÁR PROJECT.

CHAPTER I.

The Madura district—Famine—The Periyár investigations for extending irrigation. Proposals put forward; estimates and designs finally sanctioned.

THE Madura district of the Madras Presidency is bounded on the north by the Trichinopoly district, on the south by the Tinnevelly district, on the east by the Bay of Bengal, and on the west by the western ghauts. There is but one drainage system of importance in the district, the river Vaigai. The present condition of the country through which it runs cannot be better described than in the language used by Major Ryves, R.E., in a report, dated 7th August 1867.

"The principal division of the Madura district, consisting of the three taluks—Mélúr, Madura and Tirumangalam—is a strip of country running north and south; its eastern boundary marching with the adjoining zamindary estates of Sivaganga and Ramnad; and on the west separated from the Dindigul division of the district by the mountains and jungle, which extend almost continuously from Nattom on the north to Srívilliputtúr on the south, where they run into the general range of the western ghauts, which here separate British territory from the Travancore country.

"Its area, excluding uninhabited mountain and jungle, is about 1,200 square miles, with a population of very nearly half a million.

"The Vaigai river, passing through the only opening in the hills which form the western boundary, flows across the strip; the length of its course between the limits above defined being about 33 miles. In this length several river channels are taken off, most of them to fill tanks during the short and uncertain periods of Vaigai freshes. The principal channels are the Vadakarai, the Tenkarai, the Nellayoor, and the Madacolum.

"The two first have the advantage of anicuts across the river at their heads; the other two as well as all the other channels are supplied by means of temporary spurs (made of grass and sand—corumboos) run out into the river.

"The numerous tanks supplied by the channels were many of them first class reservoirs originally, but are now so silted up as to be capable of storing not much more than half the quantity of water they were designed to hold; they occupy a great deal of valuable land, and, in the attempt to get as much water as they require, the ryots of one tank frequently cause injury to their neighbours above them, damming up their escape calingulahs and flooding land by the extended waterspread.

"The tanks having become shallow in proportion to the area of the waterspread, there is enormous waste of valuable water by evaporation. I calculate that this waste amounts to at least 30 per cent. of the water stored.

"The character of the Vaigai makes the tanks system essential. For some reason or other the quantity of water received into the channel of the river bears a very small proportion to the rainfall on its catchment basin. The average annual rainfall registered at Periyaculam and Madura is 32 and 41 inches, respectively. On the Cumbum valley (where no register has been kept) it is at least as much as at Periyaculam; in the Wursanaad valley it is probably less. Taking it at 33 inches only over the whole catchment basin above the Peranny* it would amount to 3,600 millions of cubic yards per annum, and supposing that only one-third of this found its way into the streams and rivers so as to be available for irrigation there would be more than enough (with due allowance for the enormous waste on tanks) for three times the extent of paddy crop now raised.

"Yet it is affirmed by good authority that, in an average year, not a drop of Vaigai water reaches the sea; but this I think is hardly sufficiently well established to be accepted as the fact. My belief is that sufficient water for more than double the present area of irrigation does flow down the Vaigai, but that three-fourths of the annual supply passes down the river at three times the rate at which all the channels together can draw off water from it, so that if the big freshes could be detained, so as to spread over, say, 60 days, instead of running off at three times the rate in 20 days, it would be found that there would be water enough (if the tanks could contain what it would be necessary to store) for double the area of rice-crops.

"However this may be, there is no doubt as to the main fact that the supply of water obtained from the Vaigai is so precarious and scanty that even in good years the paddy crop barely covers 22,000 acres annually, although the existing tanks and channels command land enough and have sufficient hydraulic capacity, for the irrigation of fully double that extent of crop if only a sufficient supply of water, delivered at a regular moderate rate, be ensured.

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* An anicut near Madura.

"This Vaigai irrigation is situated in the Madura taluk, the middle one of the three named above. In the Mélúr taluk there is but one river, and that but a small stream, at its northern extremity, under which a small extent of land receives a good and certain supply. All the rest of this taluk is dependent for irrigation on the local surface drainage, stored in small shallow tanks, the majority of them being mere ponds. Situated as all the land of this taluk is within a few miles of the watershed, there are no well-defined streams; the Allighiry hills form a dyke turning all the hill streams to the north and south round the flanks of the taluks.

"The North-East monsoon from which this taluk receives what rain it does get, is very uncertain so far south and inland, and the mountains to the west of it (the streams from which, as above shown, do not flow through this taluk) no doubt draw away from it a considerable portion of the rain cloud which may have travelled so far.

"Under these circumstances it is not surprising that agricultural operations are seldom rewarded by a good crop. If the ryot is so fortunate as not to find the ground as hard as brick at the ploughing season, the chances are that rain necessary to bring the crop to maturity will not fall at the expected time.

"And the cultivation of wet crops is hardly a less precarious business, failure being attended with greater loss, and success attained generally at much expense of labour and money on raising water from wells and pools.

"Almost every alternate season is one of scarcity in this taluk, and, when an exceptionally dry year occurs, there is severe distress, and the population is thinned by death and emigration. In 1861–62, and again last year, it suffered severely in this way."

The records of the district make constant allusions to famine and scarcity, though information of the expenditure for this cause is not available till comparatively recent years. During the famine of 1876–77 Rs. 4,32,170 was expended on relief works and Rs. 7,92,047 on gratuitous relief in the Madura district, while in the neighbouring districts of Trichinopoly and Tinnevelly, which are partially protected by irrigation, the expenditure on relief works was Rs. 3,85,394 and Rs. 1,48,110, respectively, and on gratuitous relief Rs. 1,20,626 and Rs. 1,27,901. Moreover in a district already containing considerable irrigation works the expenditure is far more usefully employed. The loss of revenue and of life are quite beyond computation.

While such is the condition of the Madura district, on the other side of the watershed line on the western ghauts is an enormous area of uncultivated and uninhabited jungle, with a large and unfailing yearly rainfall and with great quantities of water running to waste. Among the rivers receiving this drainage is the Periyár. Its sources lie in dense unsurveyed jungle and are not accurately known, but it rises about 50 miles north-west of Palamcottah, approximately in N. Lat. 9° 10′, and runs from south to north till it reaches N. Lat. 9° 31′, where it turns due west for a short distance, during which its course is parallel to the watershed and within a few miles of it. It then resumes a northerly direction gradually trending westwards, and eventually plunges over the edge of the ghauts and reaches the sea near Cochin. It is in the short westward course commencing in N. Lat. 9° 31′ that the investigations for the utilisation of this river were conducted.

Flowing as the Periyár does through a tract of country entirely uninhabited no accurate observations of the rainfall as compared with the run-off have been made. The following table is compiled from the nearest stations at which observations are made, but no deduction from them is reliable, partly because these stations are themselves some distance away, and partly because even if they were nearer the rainfall throughout the western ghauts often varies enormously within a few miles. At Peermaad, which is less than 20 miles west of the subsequent site of the Periyár dam, the annual rainfall often exceeds 200 inches. At Thekadi, which is but 6 miles away, the fall differed considerably both in amount and distribution from what was afterwards observed at the Periyár. For the same reasons the observed rainfall at the dam site or near it is no measure of the fall over the whole catchment:—

Month.	Average recorded rainfall at					
	Cochin.	Trivandrum.	Augustamalai.	Average.	Average depth run-off from Periyár catchment in 1868–72.	Estimated rainfall at 1·8 depth run-off.
January	·34	·56	6·23	2·38	2·92	5·26
February	·65	·39	2·28	1·11	1·54	2·77
March	1·93	1·91	3·18	2·34	...	...
April	5·30	5·48	7·41	6·06	...	...
May	13·34	8·87	30·66	17·62	...	...
June	28·05	11·84	28·64	22·84	...	...
July	22·47	8·28	30·96	20·57	7·81	14·05
August	12·77	6·11	21·86	13·58	4·22	7·60
September	8·48	4·44	16·46	9·79	3·63	6·53
October	12·63	10·05	26·04	16·24	3·29	5·92
November	4·32	5·56	15·58	8·49	11·34	20·41
December	·88	1·52	9·72	4·01	3·18	5·72
Total ...	111·16	65·01	199·02	125·03	...	68·27

The average of the three stations in the above table is 125 inches per annum, and the average as deduced from the run-off observed during the investigations from 1868–72 is 68 inches. The proportion of run-off to rainfall may be considered high, but it must be remembered that the area of the catchment is comparatively small and in great part sheltered from the sun by forest, there are many cloudy and misty days during the year, the country is mainly ridges and ravines, and composed of rock lightly covered by soil, and tributaries have all rocky beds. For purposes of calculation both of floods and of the total available quantity of water the rainfall over the whole catchment has generally been taken at 100 inches per annum, since the fall during the South-West Monsoon was known to be greater, at the site of the dam, than the computation from run-off. There is reason however to believe 100 inches to be somewhat over the mark. The records maintained at the dam during its construction show an average of about 76 inches, and it was observed that the fall due to the South-West Monsoon decreased sensibly during its progress eastward. In the most easterly portions of the catchment the North-East Monsoon doubtless brings more rain than that recorded at the dam site, but its duration is comparatively so short that it probably does not make up for the easterly decrease of the South-West rainfall. Assuming the average to be 70 inches or 80 inches and the catchment to be 250 square miles, the whole of this quantity at any rate, less evaporation and small minor abstractions, falls into the Periyár, because of the impervious nature of the subsoil; and though the rainfall is variable it never fails altogether. There is obviously then an amount of water flowing down the Periyár sufficient for a large area of irrigation, could it only be diverted to the plains of Madura, and this was the object of the investigations now to be described.

The idea of diverting the Periyár into Madura has existed for an unknown time, but merely as an idea. No enquiry was made into its practicability till 1808, when the late Sir James Caldwell visited the neighbourhood and took a few levels. He however seems to have confined himself to a diversion, pure and simple, by means of a direct cutting from the Periyár through the watershed, and finding a rise of over 100 feet between these two points he condemned the project as "decidedly chimerical and unworthy of any further regard," which as thus conceived it undoubtedly was. The subject was mooted in a desultory manner from time to time, and in 1850 a small dam and channel were actually begun for diverting a small tributary of the Periyár, the Chinna Muliyár, but the work was stopped by fever among the coolies and by the excessive wages demanded by them, a forecast of two of the principal obstacles which were afterwards encountered.

It was not till 1862 that the project was revived by Major Ryves R.E., in a practical form. This officer and Major Payne spent several seasons in local investigations, experiencing great difficulty from the uninhabited and inhospitable nature of the country, the incessant rain, the absence of paths, the dense jungle and elephant grass, and the swarms of leeches; and also from the fever which was exceedingly rife during the dry months. In 1867 Major Ryves submitted detailed proposals including an earthen dam 162 feet in height at the site marked No. 1 in the map. An escape was to be made at 142 feet above the river-bed, and the water was to be diverted into the valley of the Vaigai by a cutting through the watershed at the point marked A, having its sill 17 feet below the escape crest and a maximum depth of cutting of about 52 feet. No provision was made for controlling the discharge through the watershed cutting; but in order to prevent a flow into the Suruliyár * beyond what that stream could safely carry, it was proposed to construct a reservoir with a capacity of 945 millions of cubic feet at some point not fixed between the Suruliyár and the watershed. No other provision for storage was made, the project being essentially one for the diversion of the river and not for storage of water. Then, as afterwards, the principal difficulty was foreseen to be the control of the river during the construction of the dam, and it is interesting to note the manner in which Major Ryves proposed to deal with it. The unhealthiness of the country limited the working season to the period between June and February and the dryest and best months of the year were thus lost for working in the river-bed when the discharge was at its lowest. The high discharge during the South-West and North-East Monsoons still further limited the time available for foundations to a possible 30 days in August and September, and the 3½ months commencing with December. Starting with these premises Major Ryves proposed to begin work in June by depositing large rough stone in the river-bed to a height of +32, leaving a clear opening of 45 feet on the left flank through which he judged the river would flow with a velocity of about 5 feet a second, with a surface level of + 3. As soon after the North-East

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* The large tributary of the Vaigai in whose bed the Periyár was to flow.

Monsoon as the discharge fell to 750 cubic feet a second the surface level would be raised to +12 by a temporary dam across the 45 foot gap, the water flowing through the interstices in the stone dam. In the comparatively still water thus induced a front bund (*a*) was to be made by depositing earth from boats to a level of +8. Four syphons 4 feet diameter were then to be put up and filled, to take the whole discharge of the river; the temporary dam across the gap was to be removed, and the surface level in front would fall to +8 leaving the top of bund (*a*) dry, it being protected during the fall of the water by a covering of halved bamboos lashed together and weighted with stones. A rear bund of earth (*b*) could then be completed and the enclosed space pumped dry.

The bottom layers of puddle lining and of the main earthen dam could then be carried on inside, and at the same time the front and rear bunds (*a*) and (*b*) and the stone dam raised. When the front and rear bunds reached +20 and +15 two of the syphons were to be raised, followed by the other two, and their former positions made good. The whole was thus to be raised in two foot layers, the bunds (*a*) and (*b*) always 5 feet to 10 feet higher than the enclosed space, and the stone dam 15 feet higher, with a corner always left open for the discharge of casual freshes. By the middle of February Major Ryves calculated that the earth and puddle would have reached a level of +25, and the stone dam would be continued across the gap and be at a level of + 42. In this condition he intended to leave the work till the next season, the rear bund (*b*) being covered with halved bamboos loaded with stone, his computation being that the proportion of the river discharge which percolated through the stone dam would have a velocity of only 1½ feet a second, while that flowing over the top would run at about 6½ feet a second. A certain amount of damage would, he allowed, occur to the rear slope of the stone dam, but not enough to materially endanger it.

So far as Major Ryves' observations showed the stone dam at this level was capable of passing through its interstices the whole discharge of the river from June to November for 9 days out of 10. He therefore considered that this dam might be continued throughout the whole of the working season, and also the earth and puddle on one flank. During the dry season the latter would be brought up to a uniform level the whole way across, and in this manner he calculated that by the fourth season the work would be brought up to the level of a saddle at + 110, across which all the water would then be passed, and from this point onwards the stone dam in rear could be discontinued. On the completion of the main dam the saddle was to be built up with masonry to a level of +142, at which it would be left as a permanent escape. He even believed that the whole work could be completed in four seasons, or in three if very dry and favourable, but he thought it advisable to allow the longer period in order to give the earth plenty of time to settle.

The approximate cost Major Ryves placed roughly at the following figures:—

	RS.	
Preliminary works	11,000	Rs. 17,49,000.
Dam and escape	8,67,000	
Cutting through watershed ..	3,12,000	
Regulating reservoirs	75,000	
Works in the Suruliyár	80,000	
Distribution works	4,04,000	

These figures, as well as the general proposals, are instructive as showing in how gradual a manner a true appreciation arose not only of the magnitude of the scheme and the expense attending it, but also of the special difficulties and uncertainties that must inevitably attach to its accomplishment. But those were the days when the name of Arthur Cotton was fresh in the land and the Gódávari and Kistna Irrigation Projects had just been successfully established, and it was the tradition of the Madras Engineers to shrink from no task, however gigantic, and to make light of all obstacles.

The details of the scheme described above came in for considerable criticism, although there was a general consensus of opinion as to its advisability; but it was recognised that the available information was as yet insufficient, and further investigations were committed to the charge of Lieutenant Pennycuick, R.E., and, after that officer's departure to England on medical certificate in 1870, to the late Mr. R. Smith; and during their enquiries a certain amount of road and path-making was carried on in the neighbourhood to improve the communications against the time when they should be wanted and to accustom labourers to the strange environment. As the situation grew clearer it became evident that the expense would be much greater than had been imagined and that it would be hazardous to attempt to control the river during construction in the manner proposed by Major Ryves. Though the essential features of his scheme were retained numerous modifications were suggested. These were principally of the nature of culverts under or through the dam or tunnels round the flanks, and laboured under the disadvantage of enormous cost as long as the dam was of earth with a very wide base and the necessity of allowing no water to flow over it was paramount. The inherent disabilities of an earthen dam more than 150 feet high were considered to have been overcome by the use of the "Silting process," of which much was at that time expected. Meanwhile two new sites, marked 2 and 3 on the plans, were examined and found to possess material advantages over No. 1, but these were ultimately abandoned in favour of the site marked 4, 7 miles lower down the river, which was, in many respects, superior to all the upper sites. The river bed here is 34 feet lower than No. 1 site, but, by its adoption, the water can cross the watershed at the point marked B, which is 47 feet lower than A, showing a saving of 13 feet in the height to be overcome. The ground between the sites 1 and 4 is flat and open as compared with that above No. 1, so that a dam 168 feet high at No. 4 stores more than double the quantity impounded by a dam of 220 feet at No. 2, while the drainage area available is 305 square miles against 250. No. 4 site was therefore definitely adopted, and it was further decided that the relative levels of dam and offtake should be such as to allow of the storage of sufficient water to overcome all fluctuations in the discharge of the river, and to allow a regular equable supply to be passed, under complete control, into the Suruli valley. A project complete in all details was finally submitted by Mr. R. Smith in April 1872. His proposals included—

(1) A dam, 175 feet in height, to be constructed of earth by the silting process, with an escape 400 feet in length blasted out of the saddle on the right flank of the dam. The construction of the dam involved, as a subsidiary work, the excavation of a tunnel 423 feet in length with an area of 1,064 square feet, with cuttings at each end aggregating in contents nearly 4½ millions of cubic feet for the passage of the water temporarily.

(2) A tunnel 7,000 feet in length under the watershed ridge, with cuttings at its two ends. The sill of the cutting on the lake side was to be 113 feet above the river bed, the space between this level and that of the escape crest (+ 144) allowing 6,815 millions of cubic feet of water to be stored. For controlling the entrance of water into the tunnel an elaborate system of regulating sluices estimated to cost Rs. 71,000 was provided.

(3) A series of regulating sluices for passing the Periyár water round the flanks of the various anicuts on the Suruliyár.

(4) Works for the distribution of water for the irrigation of 150,000 acres of land in the Madura and Mélúr taluks.

The total cost of the project was estimated at Rs. 58,99,700, exclusive of interest, indirect charges, and any payment to the Travancore Government for the use of the water. The returns were estimated at Rs. 6,94,000 less 10 per cent. for maintenance.

Mr. Smith's proposals were generally approved, but the execution of the project was opposed by General Walker, R.E., then Chief Engineer, mainly on the ground that sufficient experience had not been gained of the silting process to justify entire confidence in it for a work of such magnitude. He suggested certain qualified proposals, some of which had already been considered and rejected; and further consideration showed that the project must be carried out in its entirety or not at all.

The advisability of constructing a masonry instead of a silt dam was also mooted, and a further report was called for from Captain Pennycuick and Mr. Smith. Mr. R. Smith stated that he had at one time been in favour of a masonry dam and that he would have prepared a detailed estimate for it when maturing the Periyár scheme, had not his approximate calculations indicated that such a structure would be too costly to recommend. He considered that to close the valley with a wall of first-class rubble masonry would require an outlay of 19 lakhs of rupees, and he assumed that such masonry would cost over Rs. 29 per 100 cubic feet, while his estimate for the silt dam was 5·226 lakhs of rupees. Of all the estimates submitted from beginning to end it may be remarked that this of Mr. R. Smith's for a masonry dam was by far the nearest to the actual cost eventually incurred. Captain Pennycuick reported more at length, first on the arrangements for passing the river freshes under the dam during construction, and secondly on the substitution of masonry for earth or silt. As to the first point his estimate for an area of 1,064 square feet was—

	RS.
For a tunnel	5,63,500
For a masonry culvert	5,20,000
For a cement concrete culvert	7,50,000

For an area of 600 square feet his estimate was—

For a tunnel	4,50,000
For a masonry culvert	3,00,000
For a cement concrete culvert	4,20,000

With regard to the second point Captain Pennycuick proposed a dam with section based on Molesworth's formula and having front and rear faces of solid masonry with longitudinal and cross walls of the same materials, 6 feet thick, the cells formed by these walls being filled with concrete.

These arrangements and the details of construction were objected to as involving risk of unequal settlement, and Captain Pennycuick in later proposals gave the objection due weight. He also reconsidered the question of allowing the freshes to pass over the dam during construction or of passing them under it, and in the event of the latter arrangement being preferred he proposed to form culverts having a waterway of 1,800 square feet so as to reduce the velocity of discharge. This was a matter of importance, since the highest then recorded flood represented a discharge of nearly 50,000 cubic feet a second, involving a velocity even with this area of nearly 28 feet a second. It will be seen that two principles were gradually being established, first that it was practically impossible to prevent the occasional submersion of the dam during construction, and second that this precluded the idea of an earthen dam in any form. At that time large masonry dams were little known to any but French Engineers, and the hesitation in admitting the necessity for one is easily comprehensible.

The Government of Madras wished the whole matter referred to the best English opinion and with this recommendation forwarded the estimates to the Government of India. The latter, however, considered that the experience of Engineers in India in the construction of irrigation works must far exceed that of Engineers of any other country in the world and they offered to appoint a committee of high standing, selected from Bengal, to which an officer of the Madras Public Works Department having complete knowledge of the locality and of the details of the project might be added. This not meeting the views of the Government of Madras, the enquiry into the probable returns of revenue not being completed, and the severe famine of 1876-77 at that time occupying all funds as well as all attention, the matter was temporarily put aside, but meanwhile the Revenue Department continued their enquiries and ultimately reported that an eventual net return of Rs. 5,99,000 per annum might fairly be looked for.

No further action of a practical nature was taken during the ensuing six years; but there was a great deal of desultory discussion, in the course of which the arrangements gradually took a definite and less debatable shape, while the conviction that the substitution of masonry or concrete was a necessity deepened in the minds of all the officers who considered the subject. Finally the whole of the papers were handed over to Major Pennycuick, who was directed by an order, dated the 8th May 1882, to be relieved of other duty with a view to his undertaking the revision of the plans and estimates for the entire project; and this officer submitted in the same year a report, with detailed estimates which were eventually sanctioned. Such of the proposals as relate to the head works are here reproduced in extenso, in order to mark the departures which took place during actual construction.

" The height of the dam proper is to be 155 feet from the bed of the river, with a parapet 5 feet in height and 4 feet in thickness. The thickness of the dam proper is to be 12 feet at the top and $115\frac{3}{4}$ feet at the lowest part. It is to be constructed throughout of concrete, composed of 25 parts by measure of hydraulic lime (ground but not slaked), 30 of sand, and 100 of broken stone.

" The front face is to be plastered with plaster composed of equal parts of lime and sand.

" The lime will be ground, the stone broken and the concrete mixed by machinery driven by a turbine, the power for working which will be obtained from the river itself.

" The concrete will be conveyed from the machines to the point where it is required for use by a wire tramway, and rammed by machine.

" A temporary dam, 30 feet in maximum height, will be constructed above the site of the main dam, and a similar dam 10 feet in height below the site to enable it to be completely cleared and the foundation trenches blasted out before the main dam is begun. These dams will be constructed of material similar to that of the main dam.

" In order to provide for the passage of river water during construction, two culverts with an area of 96 square feet each will be cut through the rock on the left bank of the river; they will be closed by an equilibrium shutter with gearing so designed that the velocity through the culvert can never exceed 20 feet per second, but that subject to this limit the gate shall open or close 3 feet for every foot of rise or fall in the level of the water above the dam.

" On the right bank will be a similar culvert with one-fourth of the area for supplying the turbine which drives the manufacturing machinery. The gearing of the shutters of this culvert will be so arranged that, under ordinary circumstances, it will pass only the amount of water required for the turbine, but that on emergency it may be made to pass any quantity up to a maximum of 960 cubic feet a second, giving a maximum velocity of 20 feet per second.

"The two culverts will thus pass if necessary 4,800 cubic feet a second, and so long as the discharge of the river does not exceed this amount (that is, for 19 days out of 20), the water level above the dam may be maintained at any desired level, from which it will not vary by more than 2 feet at the most.

"For the formation of escapes two saddles, one on each bank, will be utilised. That on the right bank has solid rock at a minimum level of + 154 and will be cut down for a length of 420 feet to a level of + 144.

"On the left bank the solid rock is at a level of + 104, and the saddle will be built across with material similar to that of the main dam to the same level (+ 144) as that of the right bank escape. The wall thus formed will have a length on its crest of 403 feet; and a further length of 97 feet, making 500 feet in all, will be obtained by cutting away the rock at its two ends. The two escapes will thus have an aggregate length of 920 feet. At a distance of 60 feet from the escape wall on the left bank will be built a second wall 10 feet in height, with its crest 30 feet below that of the first wall, to form a water cushion.

"In the valley of the Muliapanján (a tributary of the Periyár on the right bank) a cutting will be started at + 113, running northwards, 21 feet broad with a fall of 1 in 440. When the depth of the cutting (in rock) reaches 30 feet, which will be at a distance of 5,400 feet from its starting point, it will be replaced by a tunnel with an area of 80 square feet and a fall of 1 in 75. At its lower end the tunnel will communicate with the bed of the small stream, up whose valley the Gúdalúr Ghaut Road now runs, by a cutting similar to that at its southern end. The length of this cutting will be 160 feet and of the tunnel 6,650 feet.

"At the entrance of the tunnel will be placed an equilibrium sluice similar in principle to that used for the escape culverts under the main dam, by which the discharge can either be regulated at pleasure or maintained automatically at any fixed amount.

"The existing Gúdalúr Ghaut Road on the main line of communication between Madras and Travancore passes close to the mouth of the tunnel, about 8 miles from the site of the dam. From this point a road will be constructed to the dam for the conveyance of materials, stores, &c. Traction engines will be used for the purpose, as the nature of the ground admits of a remarkably favourable trace, there being no gradient against the traffic of more than 1 in 600, while fuel is cheap and animal power exceedingly dear. For the conveyance of lime, grain and all materials which can be carried in small parcels up the ghaut a wire tramway will be used, the ghaut road being only used for articles too heavy to be carried in this manner.

"The working season in the Periyár valley is from the burst of the South-West Monsoon in June to the end of February, and as the few days of June which will be available for work will usually be absorbed in the collection of labour and preliminary arrangements for the season's work, the net working time is taken at 8 months of 25 days each or 200 days in all. The head works are estimated to take five seasons in construction, besides one of preliminary work which will be taken up by the construction of the road and laying out of the buildings, clearing of ground, and similar matters. The cuttings of the escape culverts and the erection of machinery will be taken in hand immediately on the opening of the following season, and during August and September when the discharge of the river is small the temporary dams will be built. By October of this season it is expected that the actual construction of the main dam will be begun.

"The surveys show clearly enough that there is no site above that chosen which can in any way be compared to it, it is also known that there is no depression in the watershed ridge lower than that at the Gúdalúr Ghaut head, while the fall of the river below the site is exceedingly rapid (25 feet per mile) and it turns away in a north-westerly direction, thus diverging from the watershed ridge. The rock, both in the river bed and on the watershed ridge, is a hard sienite, free from fissures, and suitable both as a foundation for the dam and a material for its construction.

"The levels of escape crest and cutting sill are the same as thos provided in Mr. Smith's project, which are the most suitable taking al points into consideration, whether the dam be of earth or masonry. I order to store the same amount of water between the sill of the cutting an the crest of the escape the relative levels would have to be—

Cutting sill.	Escape.	Top of dam.	Cost.
			LAKHS.
0	115	130	38·38
25	116	131	35·94
50	120	135	32·13
75	127	141	29·14
100	137	150	27·85
110	142	154	27·60
120	148	159	27·76
130	155	166	28·34

"There is very little variation in the total cost between the 100 and 12 levels; the level chosen is, on the whole, the most economical, and has th additional advantage that it gives a length of tunnel and a content of da which can conveniently be executed in the same time without the use of shafts for the former.

"Most modern dams of any magnitude have been built of uncoursed rubble masonry. Concrete is nothing more than uncoursed rubble reduced to its simplest form; as regards resistance to crushing or to percolation the value of the two materials is identical, unless it be considered as a point in favour of concrete that it must be solid, while rubble may, if the supervision be defective, contain void spaces not filled with mortar. The selection between the two depends entirely on their relative cost. In many cases, probably in the majority, the cost of preparing the stone and of mixing and laying the concrete exceeds that of building the rubble, the quantities of materials in both being practically identical. At the Periyár, however, skilled labour is abnormally expensive and difficult to procure in large quantities, while the facilities for the use of labour-saving machinery, which can be largely used in the manufacture of concrete, are unusually great. On this ground after full discussion it has been decided to adopt the latter material.

"The analysis of the lime to be used shows a great similarity to the well-known 'Theil' lime employed on all the large dams near St. Etienne and on the Suez and Port Said harbour works. A limit of crushing resistance equal to that allowed in the French dams may be accepted. The principle on which the pressures on the rear slope are calculated forms the subject of a separate note; calculated on this principle the Ban dam has a maximum pressure of 17,985 lb. on the square foot, and the La Terrasse 19,783 lb. I have not been able to obtain a section of the Furens dam in sufficient detail to enable the pressure to be accurately calculated, but it is about the same as in the Ban, or about 18,000 lb. on the square foot. The section designed by Rankine in his memorandum in connection with the Bombay water works would have a maximum pressure of 22,058 lb. It is considered therefore that the limit of 18,000 lb. may safely be adopted, and the section has been designed to fulfil the following conditions:—

(1) That the lines of pressure shall always fall within the middle third of the dam.

(2) That the pressure on neither face shall exceed 18,000 lb. on the square foot.

"With the reservoir entirely empty, there will be a trifling excess of pressure on the front face, but this case will not occur in practice, as the water level will never fall below 113 feet above the river bed, and the conditions would be fulfilled even were it 28 feet lower than this. During construction the water level will be raised to + 90 or + 100 before the upper 30 feet of the dam is built.

"The quantities have been estimated on the supposition that every hundred cubic feet of concrete will require 60 cubic feet of solid stone *plus* 10 per cent. for wastage, 25 cubic feet of unslaked lime and 30 cubic feet of sand. The two latter materials will make 45 cubic feet of mortar, so that the allowances are rather in excess of what will be wanted in practice. Surki is not required, the lime being naturally hydraulic. Excellent sand is procurable from the bed of the river."

Then follows a detailed description of the machinery with which Captain Pennycuick proposed to break the stone, prepare mortar, mix concrete, convey it to the workspot, and ram it. Such of this machinery as was eventually used will be treated separately. As to the motive power his report is as follows:—

"The circumstances so obviously enjoin the use of water-power that a discussion upon the point seems unnecessary, but it may be worth while to state briefly the relative cost of water and steam for the 200 H.P. required at the dam site. The cost of the former is—

	Rs.
Turbine, shafting, &c.	15,000
Repairs and maintenance	6,000
Labour	3,000
Culverts and regulating gear	14,000
	38,000
Less the stone used in the installation, otherwise available for the dam	8,700
	29,300

or Rs. 146½ per horse power.

For steam the cost would be—

	Rs.
One 20 H.P. portable engine	7,500
Repairs and maintenance	2,500
Belting, &c.	1,500
Fuel, lubrication, and water	6,500
Attendance	2,000
Total per 30 net H.P. ...	20,000

or Rs. 567 per horse power.

"A single fixed engine would be rather more economical as to first cost, fuel, and attendance, but the cost of setting and foundations would be very great, and for many reasons if steam were used at all it would be in the form of a number of portable engines. The difference between the cost of steam and that of water would thus be not less than Rs. 94,000, while the latter has the additional advantage of being capable of increase fully 30 per cent. if required, at a merely nominal expense.

"The length of the right bank escape is fixed by the quantity of stone required for the dam. The total required is 3,600,000 cubic feet, of which 1,400,000 are brought from the watershed cuttings, the cost of conveyance being less than quarrying afresh. About 600,000 cubic feet is available from the temporary escape cuttings, from the foundation trenches, the left bank escape, and from boulders and loose rock removed in clearing the ground, leaving a balance of 1,600,000 cubic feet to be obtained from the right bank escape. The length required to give this quantity is about 420 feet, making with the escape on the left bank a total of 920 feet.

"Taking the total at 900 feet and the discharge from the highest recorded flood (a very remarkable flood indeed) it is calculated that the water level would be raised to +153·15. The level of +155 has, therefore, been taken as the maximum for which the dimensions of the dam are calculated.

Method of disposing of water during construction.

"The method of disposing of the water of the river during construction has been the subject of much discussion, and as there has been some misunderstanding as to the objects to be attained by the temporary escapes, it seems desirable to consider somewhat at length what these objects really are.

"In an earthen dam it is essential that under no circumstances whatever shall a drop of water ever pass over the top of the dam, and, given the discharge of the river and the rate at which the work can proceed, the area of escape necessary is a matter of direct calculation.

"In the case of a masonry dam, however, the conditions are entirely different; it is necessary that the water should be diverted so as to allow the bed to be laid bare and the foundations properly put in; but for this, which can, if required, be done at a dry time, a very small area of escape culvert is required, and once the foundations are fairly in, there is no *necessity* for diverting the river at all. It is only necessary to screen off the particular portion of the dam which happens to be still unset, and the water may be allowed to pass freely over the remainder. As a fact, many dams, both in Europe and in India, have been constructed in this manner.

"The passing of the water under rather than over the dam is purely a matter of convenience and economy—convenience as avoiding too frequent interruptions, and economy because it may very well be that the constant shifting of frames and protective apparatus will actually cost more than an escape culvert of moderate size.

"It is obvious then that no comparison of the areas of culvert required for a masonry dam and for one of earth has any value; for the latter we must spend whatever sum may be necessary to prevent all chance of its being submerged, for the latter it would be folly to spend a couple of lakhs of rupees to prevent a submersion which may possibly cost a thousand.

"It is evidently impossible to fix with anything approaching mathematical precision what is the particular area of escape culvert which will give the right degree of protection without undue expense; the principle on which the dimensions actually proposed have been arrived at is that the culverts should be capable of passing without submersion of the work, all discharges of which we have records in any months except July and November, that is, that the possible interruptions should be confined to those two months, and that the velocity through the culverts shall not exceed 20 feet per second.

"The area of culvert necessary to fulfil these conditions depends upon the amount of storage available between the top of the temporary dam and the level at which the water is maintained during ordinary times, as it is the difference between this amount and the maximum discharge of the river during any given period which the culverts must pass.

"With a given level of temporary dam, we can, by lowering the normal water level, reduce the area of the escape culverts; but at the same time we reduce the head available for working the turbines and increase the cost of the latter, or *vice versâ*.

"On the other hand, by raising the temporary dam, we can save on the turbines or escape culverts or on both. By lowering it we reverse the process.

"The following table shows approximately (allowing for the value of stone) the cost of the temporary dams, escape culverts and turbines for various levels:—

Height of temporary dam.		20	25	30	35	40
		RS.	RS.	RS.	RS.	RS.
Normal level of water above dam.	10	64,000	67,000	69,000	71,000	75,000
	15	51,000	53,000	55,000	57,000	61,000
	20	...	49,000	51,000	54,000	57,090
	25	...	...	48,000	50,000	53,000
	30	...	...	...	50,000	53,000
	35	...	...	...	...	53,000

"There is very little difference in cost among the levels from 20 feet to 40 feet; those chosen, 30 feet and 25 feet are preferred not so much as being the most economical, as because they are, on the whole, the most convenient for practical working.

"In order to pass all discharges of which we have records, with these levels, the total area required is about 230 square feet; the area provided is 240.

"With the limiting velocity of 20 feet per second these culverts will discharge 4,800 cubic feet per second; in the three years of which we have records, there were altogether 30 occasions, of which 16 were in November and 6 in July, on which the discharge of the river exceeded this amount; on 16 of these occasions the discharge lasted only for a few hours, and would not seriously raise the water level above the dam; the effect of the remainder is shown in detail elsewhere.

"It will be there seen that, with the area of culvert adopted, there were altogether three occasions, extending over six days, on which the work would be topped during the first season, four during the second, two during the third, and one during the fourth.

"During the fifth season no flood that has ever occurred could top the work, because in that season the saddle on the left bank will be available for the discharge of surplus; and in the fourth season none except the great flood of November 1869.

"Assuming that the three seasons of which we have records represent a fair average, we may expect to be interrupted three times during November of the first season, twice during the second, and possibly once or twice during the third, with a remote chance of an interruption in the fourth.

"It will also be seen that an increase in the area of culvert from 240 to 400 square feet would only save five out of the total of ten interruptions entered, while a reduction to 200 feet would increase the number to 15.

"To prevent such a flood as that of November 1869 from passing over the work even during the third season would require an area of 2,700 square feet, the cost of which would be out of all proportion to any possible damage that could occur from the submersion of the work for a few hours.

"On the whole the area chosen appears to form the most reasonable compromise between undue risk of inconvenience and loss by the interruption of work and undue expenditure on insurance against such risk.

"It is obvious that, in order to limit the velocity through the culvert, we must either have the means of completely controlling the entrance of water thereto, or make its area so great as to limit the rise to the extent necessary for generating that velocity.

"In Mr. Smith's design the tunnel mouth was uncontrolled, and with the area given of 1,064 square feet a velocity of 45 feet per second would be generated during a flood such as that of November 1869. To keep down to the lower limit of 20 feet here proposed, an area of some 6,000 square feet would be necessary.

"It is to meet this difficulty that the equilibrium shutters shown on sheets 10 and 11 have been designed. The pressure of the water is taken entirely by the ties connecting the shutters which are adjusted so as not quite to touch the faces of the frames against which they work; there is thus no friction, and only the weight of the shutter has to be moved.

"In order to reduce this weight, four wrought-iron pipes 30 inches in diameter and ¼ of an inch thick are introduced, the buoyancy of which is very nearly enough to cause the whole gate to float; the actual downward tendency is about 400 pounds and this is all that has to be moved in order to open the gate.

"There is nothing, in the whole construction, different in kind from the work in an ordinary steam boiler and there is no more difficulty in making the whole apparatus water-tight under a pressure of 60 lb. on the square inch than in making a locomotive boiler steam-tight under double that pressure; but in order to provide against any leakage into the pipes (which would increase the weight to be moved) screw plugs are provided, which may be removed from time to time, the gates being let down for the purpose, and any water that may have leaked in may then be pumped out.

"The tension on the tie rods is 5,303 lbs. per square inch under 150 feet of water.

"The shutters will be adjusted so as to have a clearance of ⅛ of an inch between themselves and the frames at the culvert mouth, and to prevent leakage through this space when the work is completed, the frames shown in detail on sheet 11 will be introduced. By means of these frames a strip of vulcanised India rubber will be screwed tightly over the opening, and the passage of water completely prevented.

"An incidental advantage of this form of gate is that it may be used to allow the passage of water into the river below the dam, if at any time such passage should become necessary, either in order that the water may be used there, or that the lake may be emptied.

Construction of culvert.

"The entrance to the culvert up to 20 feet from the face of the main dam is formed by tunnelling through the solid rock, as it is thought that there will be less chance of percolation through the rock than through the concrete if an open cutting was made and arched over; the cost is about the same.

"It is for this portion only that the velocity of 20 feet per second is adopted; for the remainder of the length the total area is 412 square feet, and the velocity is 9·32 feet per second.

"This latter portion is simply an open cutting 16 feet wide covered by an arch with a radius of 20 feet (forming an arc of 53°) and a depth at the side of 6 feet.

Pressures on rear face of dam due to culvert.

"The support is removed from under the dam where the culvert comes in, and the pressure on the material has to be borne by the adjacent portions.

"The width of the cuttings is 16 feet and the extra pressure may be considered to be distributed over a similar distance on each side and over half the depth of the arch at the abutments; in other words, the pressure due to 48 feet has to be borne by 38, and the maximum pressure will be $\frac{48}{38} \times 12{,}741 = 16{,}094$ pounds on the square foot, the limit allowable being 18,000 lb.

"The peculiar form adopted for the entrance tunnels is rendered necessary by the steepness of the rock on this side which prevents the use of the simpler and cheaper form adopted on the right bank.

Fitting of frames.

"The excavation of the mouth of each culvert will be made a little in excess of the standard dimensions so as to allow of the easy fitting of the iron face frames; the gates will be lowered into position and the frames set up at the right distance from them, the space between the latter and the rock being then packed in with fine mortar of lime and sand in equal quantities.

Gearing for shutters.

"The gearing for working the gates is shown in Plate III.

"The gate is carried at one end of a beam 30 feet in length working on a pivot at the other end.

"Attached to a point 10 feet from the pivot end is a chain connected to a buoy of sufficient floating power to lift the gate. The length of this chain is adjustable at pleasure so as to give the opening necessary to pass the normal discharge of the river at any level at which it may be desired to retain the water surface; an increased discharge raises the water level and increases the opening; a diminished discharge has the opposite effect.

"It is necessary to prevent the gate from rising to a height sufficient to generate a velocity exceeding 20 feet per second, whatever be the head on the front face.

"The buoy A carries a light chain coiled round a drum B fixed to the bottom of the cutting; connected with the drum B is a drum C with a diameter 3/20th that of B, round which is coiled a chain passing over the pulley D and attached to the axle and rollers E; as the water rises, the rollers are drawn along by the chain between the beam FG and the lifting lever, and the travel of the latter is limited by the position of the rollers; as the water falls the rollers are drawn back by the weight H.

"The inclination and position of the beam FG is found by calculation and is such that the maximum possible lift of the gate for any water level is $\frac{32}{\mathrm{L}\sqrt{\mathrm{n}}}$ being the difference between the water levels above and below the dam; with a velocity equal to $5\sqrt{h}$ the discharge will therefore be 1,920 cubic feet per second for each culvert.

"This is the maximum discharge possible; below this limit the discharge is regulated entirely by the level of the lake, the main lifting buoy is of course submerged when the regulating gear comes into play.

"The form given to the guiding beam FG gives correct results for depths 30 feet, 50 feet, 90 feet, and 130 feet; for intermediate levels the results are not quite accurate as the face should have a slight curve instead of being a straight line, but the error nowhere amounts to more than 3 per cent.

"If a greater velocity than 20 feet per second be considered permissible, the inclination of the beam FG can be altered accordingly; but it would be unadvisable to make any reduction in the area of the sluices, as the head necessary to give this velocity is nearly as much as it is convenient to allow during the early part of the work; the extra velocity should be used to give additional discharge and reduce the risk of submersion.

Temporary dam.

"The following mode of construction will be adopted for the portion of the temporary dam which is within the ordinary water spread of the river. Cases 18 feet by 5 feet by 10 feet internal dimensions will be sunk in the bed of the river at intervals of 15 feet from centre to centre, and kept in position by iron rods jumped into the rock at their four corners; they will be made as water-tight as possible and the interior will be pumped dry and the lower part of each buttress and of the wall attached to it constructed inside them, the full height being completed in the ordinary way. A groove 6 inches broad and 1 foot deep will be left in each side of each buttress at 6 feet from the front face; there will then be a series of 18 piers 5 feet wide with openings 10 feet wide between them, extending across the river bed. Nine of these openings will be closed by shutters 10 feet high let down in front of the buttresses and in the grooves in their sides, and the spaces thus enclosed built up to 5 feet; the shutters will then be removed and the other nine openings built up in the same way to 10 feet; then the first 9 to 15 feet and so on, until the whole stream is carried by the escape culverts.

"The discharge of the river during August and September rarely exceeds 12,000 cubic feet per second, which the 90 feet of opening always left will pass with a depth of about 3 feet, so that work will not be liable to much interruption.

"The lower dam will not be begun till the upper one is finished, and being constructed in practically still water will be an easy job.

"When the lower dam is completed, the space between the two dams will be pumped dry, and the foundations of the main dam put in.

Watershed cutting.

"The watershed cutting is a work of an ordinary description, and requires no special notice; if the slope of the cutting and tunnel were the same, the latter should begin when the former reached the depth at which the cost per foot of advance was the same for both, which, with the dimensions and prices here adopted, would be 27 feet; but as the slope of the tunnel is greater than that of the cutting, the total length is diminished by reducing the proportion of the former, and it is economical to extend the cutting a little further, and the proper depth for the change becomes 30 feet as adopted.

Watershed tunnel.

"The nominal area of the tunnel is 80 square feet, but to provide against slight irregularities in the excavation an area of 84 square feet has been provided for. A heading of 42 square feet will be first excavated, and afterwards enlarged to the full area.

"It would be inconvenient to work for any distance from the upper end of a tunnel with a slope of one in seventy-five, and only 350 feet of the whole length of 6,650 feet will be thus done, the remainder or 900 days' work at 7 feet per day being done from the lower end.

"The boring for the heading for this 6,300 feet will be done by machines driven by compressed air; it could be done somewhat cheaper by hand, but in this case we could not reckon on an advance of more than 2½ feet and 3 feet per day, and two shafts would be necessary, the cost of which would more than cover any saving in boring.

"Four drills will be employed, and there is no doubt that the advance of 7 feet per day, or 74 cubic feet for each drill, can easily be obtained. At the St. Gothard the advance with six drills was from 10 feet to 12 feet on a heading with an area of 67 square feet, or from 112 to 134 cubic feet per diem for each drill. The estimates of the daily work of the drills are very moderate as compared with actual experience both in Europe and America.

"The boring for the enlargement of the principal tunnel and for the whole of that portion which is executed from the upper end will be done by hand. The heading will be kept only so far in advance of the enlargement as to prevent the workmen from interfering with one another, as the firing of the charges for both will be done at the same time.

"Artificial ventilation will probably be required after the first 3,000 feet, and provision has been made for the exhaustion of 6,000 cubic feet of air per minute. The amount of dynamite exploded daily will be about 58 lb., the gases generated by which will occupy about 20,000 cubic feet or about 1/300 part of the fresh supply in 16 hours. About 2,000 cubic feet of air per day will also be supplied by the drilling machines. At the St. Gothard, where the consumption of dynamite was about 600 lb. per day, the drilling machines supplied 5,000,000 cubic feet of air per day, and the exhausters extracted 16,000 per minute.

"About 40 horse power for 14 hours will be wanted for working the compressors, and 25 horse power for ten hours for driving the ghaut wire tramway. It is proposed to obtain this power from the Muliapanján, the stream up whose valley the Gúdalúr Ghaut runs. By a turbine placed near the mouth of the tunnel, we can easily get a head of 60 feet, so that the quantity of water required will be 8 cubic feet per second.

"This stream receives the drainage of a portion of the stream of the same name on the Travancore side of the watershed, which has been diverted into it by a dam at the point shown on the general survey, and certainly supplies more than the quantity required for six months of the season. During January and February it may fall short and will be supplemented by steam power, for which provision has been made in the estimate.

"The average discharge of the stream during the whole season is considerably more than 8 cubic feet per second; and if a site could be found where some 30,000,000 of cubic feet could be stored at a rate not exceeding one rupee for 4,000 cubic feet, this would be more economical than to use steam, but the possibility is doubted.

"It is not impossible that it may be found worth while to convey the whole of the power required for working the drills and ghaut tramway by means of electricity from the Periyár, where the extra power required can be provided at a small cost; but the information at present available as to the real cost of the electrical transmission of power is so vague that no reliance can be placed upon it.

"The entry of water to the tunnel will be controlled by the gates shown on sheet No. 16, these gates are similar in principle to those already described for the escape culverts. They have an aggregate area of 120 square feet, that of the main tunnel being only 80. The reason of this is that if, as is not unlikely, the water supply is found greater than is now anticipated, the main tunnel can be enlarged at small expense, but it would be awkward and inconvenient to enlarge the gates and entrance tunnels, which would necessitate not only sacrificing the original gates and frames, but also lowering the lake so as to leave the sill of the cutting exposed, which could not be done without opening the escape culverts under the dam.

"The transport of materials is a very important item in the cost of the work, some 80 tons of limestone and the stores and food for the whole working party having to be transported daily from the lime quarries to the watershed up a ghaut 1,200 feet in height, and some 45 tons of lime and stores, besides 1,500 cubic feet of stone weighing upwards of 100 tons from the watershed to the site of the dam.

Transport of materials.

"Estimates have been made with considerable care for all sorts of means of transport, including railway worked by locomotives and by wire rope, tramways, ordinary road worked both by steam and by cattle, and water transport; and it is found that, on the whole, the most satisfactory arrangements are those now to be explained.

Various methods considered.

"The main line of road from Madras to Travancore, of which the Gúdalúr Ghaut forms a part, crosses the watershed close to the site of the proposed works, and then diverges to the west from the valley leading to the site of the dam, and cannot be used for transport beyond the watershed.

"The lime quarries are situated at from 3 to 4 miles from the foot of the ghaut, and the quantity of stone to be carried daily is about 80 tons; this can be carried from the quarries to the foot of the ghaut by a single traction engine making five trips daily.

Traction engines from lime quarries to foot of ghaut.

"The use of traction engines on the ghaut is objectionable on account of the great waste of power in working on a steep gradient and the awkward turns and zigzags which occur in several places; the engines returning with the empty trucks could not run at their full speed of 8 miles an hour, as they can on more level ground, and 4 miles an hour would probably be as much as would be safe. Although the ghaut is only 4 miles in length it is probable that three trips daily would be as much as the engines could do. The total weight to be carried daily including a small allowance for general stores is about 200,000 lb.; and as the engines intended to be employed, which on a level will take 60,000 lb. (exclusive of trucks) with ease, would not take more than 16 or 17,000 on an incline of 1 in 16, four such engines would be necessary. The first cost of engines and wagons would be Rs. 42,000, repairs and maintenance Rs. 14,000 and working expenses Rs. 40,000; to which must be added Rs. 8,000 for the improvement of some of the worst turns in the road, and Rs. 10,000 (at Rs. 500 per mile for five years) for maintenance, as the allowance made by the Local Fund Board will certainly not keep the road in a condition to allow steam to be used economically.

Objections to their use on ghaut.

"The total cost of transport for this section would thus be about Rs. 1,14,000, a sum probably not much less than the cost of transport by ordinary carts, though there might be a difficulty in getting the latter in sufficient numbers.

Advantages of wire tramway.

"It is therefore proposed to use a wire tramway which, for such a position, possesses immense advantages. It can be worked with ease on a gradient of 1 in 4 and can be laid so as to avoid all the zigzags necessary in a road, and thus effect a great saving in distance, while there is absolutely no waste of power caused by the incline, the difference between the power required to work a given length on a level and the same length on any gradient being simply that required to lift the net paying load the vertical height between the top and bottom of the line.

"To show how great this waste is on an ordinary road, the 200,000 lb. of goods here in question would be carried over a level line of 4 miles in length with the greatest ease by a single light engine indicating 25 horse power, whereas for the same distance on an incline of 1 in 16, four engines of 40 horse power are required, showing an extra work of 135 horse power due to the incline alone, the actual difference in useful work being only $\frac{21,120}{16} \times \frac{200,000}{33,000 \times 600}$ or 13½ horse power for 10 hours, and this latter quantity with an addition of 25 per cent. for friction is all that has to be provided in a wire tramway on account of the rise.

"The length of the existing ghaut is a few feet over 4 miles; the distance from top to bottom as the crow flies is 10,400 feet; the length of tramway provided is 12,000 feet, which is rather more than will be required as it can be laid very nearly in a straight line. The first cost of the tramway will be Rs. 30,000; carriage, erection, maintenance and working Rs. 26,000, while the power required will be about 30 horse power. This, as already explained, will be provided by the same turbine as works the air compressors for the watershed tunnel, and the share of its cost debitable to the ghaut will be Rs. 4,000 making a total cost of Rs. 60,000 for the transport over this section.

Ghaut to be used for heavy articles.

"For articles too heavy to be carried by the wire tramway (or exceeding about 3 cwt.) the existing ghaut road will be used, but the movement of such articles will be almost entirely confined to a few days at the beginning and end of each season.

"Some saving in transport would be effected by burning the lime at the quarries instead of at the watershed as proposed, but it is considered that this is of less importance than the improvement in supervision effected by having the kilns above the ghaut where they will be under the eye of one of the officers employed on the work.

Head of ghaut to river.

"From the head of the ghaut to the site of the dam the superior economy of the wire tramway is less decided as there is less room for saving either in distance or cost of working; and as some means of transport capable of conveying heavy weights must be constructed, the saving in the every day work by the use of the tramway does not justify its construction in addition to such other means. These other means are water, railway and road.

Water transport.

"The first of these is undoubtedly the cheapest in every way as by a series of dams in the Muliapanján and Kythery valleys, it could be obtained at a cost less than that of a road, while as regards working expenses it would be decidedly cheaper; but it would be impossible to use it without interfering with the work in the southern cutting, and the idea has had, though reluctantly, to be abandoned.

Railway.

"A light railway would cost in working about Rs. 40,000 less than the sum estimated for the road, but it would cost in construction and maintenance Rs. 60,000 more and would probably be more liable to injury from accidental causes.

Road.

"In Mr. Smith's original designs it was proposed to keep the road above the maximum water-level of the lake, involving a length of more than 19 miles from the head of the ghaut to the dam, but this is quite unnecessary, all that is wanted being that the road shall not be liable to submersion as long as it is required for use. After the completion of the work it will be useless and even before that time a portion of it will have been superseded by water carriage.

Trace adopted.

"Starting from the watershed at a level of 168 above datum, it falls at the rate of 1 in 150 for 4,500 feet, and then rises at 1 in 600 for 6,000 feet keeping as close as possible to the side of the cutting. It runs level for 500 feet, and then rises at 1 in 600 to the saddle between the Muliapanján and Nataman's valleys, which it crosses at 23,000 feet from the watershed at a level of 143; after 200 feet level it falls 1 in 60 to the Nataman's stream, which it crosses at 27,000 feet on a level of 83 being about 21 feet above the bed of the stream.

"It is level from 26,800 to 27,800 and then rises at 1 in 600 for 6,000 to the saddle above the junction of the Kythery and Nataman's valleys, which it crosses at a level of 93; a further distance of 6,200 feet on a level completes the line.

"The total distance from the head of the ghaut to the works is 40,000 feet or a little over 7½ miles, and it will be seen that the line is exceptionally favourable, there being no gradient against the traffic except 1 in 600

Traffic to be carried.

"The work to be done during the first three seasons is the conveyance of 90,000 lb. of lime and stores from near the watershed to the site of the dam, a distance of 7½ miles and of 1,300 cubic feet of stone weighing 210,000 lb. from the southern end of the watershed-cutting, an average distance of about 6 miles.

"Two engines of the class provided will do this with three trips each per day, one from the watershed and two from the cutting, the speed being from 3½ to 4 miles an hour loaded, and 8 miles when returning with empty trucks.

Water transport to be used during the two last seasons.

"During the two seasons the water-level will be raised to about 60 feet above datum, and the engines will only be required to carry the material to the point where the road crosses the Nataman's valley, from whence they will be conveyed in boats to the dam. This shortens the distance to be run by about 2 miles, enabling the engines to make three trips daily instead of two from the cutting and to carry 1,900 cubic feet of stone instead of 1,300.

Total cost of transport.

"The actual cost of transport, including all charges, amounts to three-fourths of a rupee per ton, or Rs. 5·35 per 100 cubic feet of stone, from the cutting to the dam site, the cost of excavation at the latter being Rs. 7·50 per 100 cubic feet.

"From an economical point of view it would be advantageous to use in the dam the whole of the stone (about 1,600,000 cubic feet) excavated from the southern watershed cutting and adjacent portion of the tunnel, but it is not considered desirable to reduce the length of the escape below the 900 feet provided for."

After the submission of the estimates a somewhat academic discussion ensued as to the method of calculating the section of the main dam. A usual method, that of M. Bouvier generally followed by French Engineers, maintains that the true method of ascertaining the pressure on the material of a dam at any section is to consider the resultant of the forces as acting on a projection of the plane of the section at right angles to the direction of the resultant. Colonel Pennycuick, however, contended that the resultant does not and cannot act upon any base except the section involved, and that there is no reason for transferring the effect from the actual base to any imaginary line. The discussion was terminated by the decision to employ at any point the method which gave the greatest section. The error, if any, is therefore on the side of safety, though the difference between the two is nowhere large.

In compliance with the wishes of the Inspector-General of Irrigation, who took exception to the proposals for disposing of the river during construction, an alternative method of syphons was worked out and submitted. This plan never came to trial and need not be further referred to.

The submission of these estimates completed the investigating portion of the project, but there was still one obstacle to its execution, namely, a disagreement as to the terms on which the use of the water and the land submerged by the reservoir should be handed over.

The British Government took the ground that the water was useless and likely to remain useless to Travancore, and that the land was a piece of uninhabited jungle, not of great value even in the matter of timber and from its location practically impossible for the Travancore Government to exploit. The latter Government, on the other hand, contended that the value should be appraised by its utility to the British Government, which was admittedly high, since an expenditure of Rs. 53,00,000 was expected to bring in a return of 7 per cent. per annum. After pourparlers extending over a considerable period, which it is unnecessary to further particularise, it was agreed that the British Government should pay an annual rent of Rs. 40,000, and that the lease should run for 999 years, with right of renewal; and that, for this consideration, the British Government should receive a grant of the land alongside the Periyár below a contour line 155 feet above the deepest bed of the river at the site of the dam, to the amount of 8,000 acres or thereabouts, and also an additional area not exceeding 100 acres at an unspecified level; all water flowing into the first-mentioned tract; all timber growing on the said tract; and the fishing rights; with liberty to make a road through Travancore territory to the site of the works. All sovereign rights were reserved by the State of Travancore, and the subsequent intricacies of civil and criminal jurisdiction, abkári rights, customs, &c., constituted a source of dissension which lasted till the head works were completed.

CHAPTER II.

CONSTRUCTION OF HEADWORKS.

Preliminary works—Labour and materials—Wire ropeway—Canal—Main dam—Escapes—Tunnel—Cost—General remarks.

FORMAL sanction to the project was received in the latter half of 1887, and proceedings were commenced in September of that year with a small establishment. The weather was good and the season in Madura had been bad, so that the supply of labour was encouraging. A cooly camp and officers' camp were laid out at Tekadi, near the tunnel head, a mile from the trunk road, on a ridge surrounded by swamps, the only convenient location but one which was afterwards found to be exceedingly unhealthy. A road communicating with the trunk road was opened up, but was not continued to the Periyár itself, since it had been decided to canalise the Muliya Panján and substitute water for land carriage. A saving of Rs. 50,000 was expected from this alone, but the result was by no means in accordance with that expectation, and eventually a road had to be made as an auxiliary to the canal. In the meantime, however, a bridle path was made to the Periyár and one subordinate was located there. The line of the watershed cutting was laid out and some earthwork done, and the rock so far exposed in places as to permit blasting to be commenced, the stone being used for houses. Lord Connemara, then Governor of Madras, accompanied by Colonel Hasted, R.E., Secretary to Government, visited the works and inaugurated them by felling a tree on the site of the dam. By the end of March 1888 the preliminary work may be said to have been completed. It consisted, besides the road and bridle path and the camp above mentioned, in the construction of quarters for officers and subordinates together with a certain amount of coolie-lines, store-sheds, hospital accommodation, &c., all of which had, however, to be greatly extended before the work progressed very far. It also comprised the survey and demarcation of the site of the main dam, of the canal, of the tunnel, and of the wire ropeway up the ghaut. A small reservoir for the tunnel turbine was also prepared by building a wall across the Muliya Panján near its head in a favourable position for storage, and a commencement was made on the cuttings at the entrance and exit of the tunnel.

Here the subject of labour may conveniently be taken up, since it had by this time become evident that a change in the organisation and method of employment was essential. To encourage labour all male coolies were at first employed at a daily wage of 6 annas and not by the piece. The maistries were any men who could read or write and had the courage (or were under the necessity) to enter this unknown land. They were without exception quite ignorant of their work, though there were men among them who afterwards became very useful. The officers and subordinates were insufficient for the incessant demands on them, and it was soon discovered that the earthwork was costing over 500 per cent. more than the estimated rate and this only for top soil with a small lead and in fine weather.

The coolies were, therefore, divided into gangs and put on piecework and immediately left the place almost to a man. To dispose of this subject it may be said here that the piecework system was of course persisted in and the organisation of labour was a long and difficult affair. Advances had to be made and mutually beneficial relations established with a good class of coolies, and it was not till 1890 that the supply became at all adequate. The delay and inconvenience were of course very great and added not a little to the cares of the staff. A great number of the coolies came from the Cumbum valley in the Madura district and were within reach of their homes. The high wages necessarily paid gave them a command of money to which they were unaccustomed, and the temptation to return frequently to their villages and enjoy themselves was too powerful to be withstood, and every festival of any importance was a welcome excuse. Most or all of these coolies were pledged to money-lenders and ryots from whom they had received advances in cash or grain, and they returned unfailingly at ploughing or harvest time to work off their debts, with an honesty that was admirable from one point of view, but most vexatious from another. As the works advanced a better and more permanent class of cooly was obtained from Tinnevelly. These had less temptation to irregularity, and working (in a manner somewhat unusual) in gangs on a co-operative system greater dependence could be placed on their movements. These coolies came up regularly during July and took up on piece-work nearly the whole of the concrete in the main dam, at which they worked steadily till the end of March. They were the backbone of the labour, and the relations between them and the works were mutually profitable.

In 1889 and again in 1890 detachments from the First and Fourth Pioneers were lent for service at the Periyár. While labour was scarce, bad, and ill-organised, the Pioneers were of great service and the officers made a welcome addition socially. Certain drawbacks however attached to the arrangement. The men being of course under the orders of their own officers only, were sometimes difficult to supervise effectually unless working in large bodies, which was not always practicable. Having fixed hours they were also not always available on an emergency and were generally reluctant to work over-time even at the most critical junctures. The quality of their work was also very unequal and they were expensive, and occasional unpleasantnesses and differences occurred which it required tact and forbearance on both sides to prevent from becoming serious; while the exigencies of military service sometimes clashed with the interests of the works. After 1890 therefore the services of the Pioneers were not utilised, and labour having by this time become more regular and abundant the loss was not markedly perceptible.

As regards skilled labour the conditions were, on the whole, easier than was anticipated. From the first there was no serious trouble about carpenters, since a supply of Portuguese under a most excellent foreman named P. Fernando, was obtained from Cochin. Occasionally it was wished that the number could have been greater, but though these carpenters were kept very fully employed and often had to work overtime and at night they were generally enough or nearly enough for the calls upon them. They were capital workmen, handy, willing and honest, and some of them being sailors and all more or less accustomed to water from their childhood they were of the greatest service for many other purposes than pure joinery. A great part of the work in water connected with the numerous coffer-dams, temporary sluices, timbering, shoring, and scaffolding, fell upon them, frequently by night and in the rain and cold, and they were always willing and knowledgeable. From beginning to end they were of the greatest service. They were sober, quiet, religious men, and it was a pleasure to work with them.

Masons are a far less pleasing topic. Masons all over the world seem to need more supervision than any other class of artisans, and Indian masons are perhaps at the head of the profession in this particular. The rate of pay was necessarily high and any ambitious cooly who could borrow or steal a pair of old boots and a trowel presented himself unblushingly for the job. Their sole idea was haste and the quality of the work turned out by them was such that the most stringent supervision and severe penalties were required. The rubble masonry at the Periyár may be said to vary from fair to good, and certainly resisted admirably all the vicissitudes to which it was constantly exposed, but this result must be admitted to be due principally to the excellence of the materials and the watchfulness of the staff, and was attained in spite of, not because of, the masons. In the early days few masons were available and most of the temporary work in the river-bed was done by 'Wudders' from the Madura district. These men have no real knowledge of masonry, their nearest approach to it being revetment work and an occasional rough wall of stone in clay. Being, however, accustomed to quarry, break, and handle stone they were useful for the class of work required in the temporary piers and the dams in the river-bed. Shortly after them a gang from Cutch turned up, unexpectedly, and did good work on the foundation enclosures. They speedily found out, however, that keeping shops in the camp and selling to the coolies at 200 or 300 per cent. profit was easier and more lucrative, and most of them turned their attention to this and to the acquisition of large herds of buffaloes. A few remained on the works as "Jaddi-men," *i.e.*, carriers of heavy weights by poles and slings, and these were useful among the machinery. Later on a good many masons were attracted from Coimbatore and from Madura, and though there were seldom more than a hundred all told, they were from this time generally enough for current requirements, but in the case of damage to temporary works or breaches in the turbine channel to the workshed, masons had to be diverted from their legitimate work on the upstream and downstream faces of the main dam. Throughout the duration of the work the want of elasticity in the supply of labour was seriously felt. The Periyár is so barbarous and so far from everywhere that nothing could be got on a sudden, and unforeseen emergencies had to be met always from the material and personnel which happened to be on the spot at the moment.

In a work of this nature a vast amount of quarrying was required, and in this particular little difficulty was experienced. Drillers are numerous both in Madura and on the West Coast, and the supply was adequate and the rate moderate. These men worked mostly single-handed and used the "jumper" or vertical drill raised and dropped on to the rock. Where specially deep holes were wanted two men sometimes worked at a long drill, but generally it was found that a 3′ or 3½′ hole was the deepest they could economically produce. They were useful labourers and gave little trouble, their principal drawback being that they could only drill vertical holes of not more than 1″ in diameter. A bigger bore would have led to considerable economy in explosives. In the tunnel machine-drills were almost exclusively employed, and these were worked by men who had done similar work elsewhere and were brought by the tunnel foreman under whom they had served before. On occasions when the machine drills were unavoidably stopped or in places where they could not be profitably used these men worked double-handed with a short drill and hammer. Their duty, in wet and cold and a foul atmosphere, was arduous and necessarily well paid. They displayed a deep and well-founded confidence in the tunnel foreman and were not at any time a cause of anxiety.

Coolies, masons, carpenters, and drillers have now been touched on and the only other remaining class of labour of importance is drivers and fitters. These gave perhaps more trouble than all the rest together. It was found impossible, at any reasonable rates of pay, to get together a staff at once capable and reliable. Many of the men of this class who came to the Periyár were men with a history, and these almost invariably alternated spells of good work with outbreaks of a more or less serious nature. Some of the drivers and fitters were caught very young and practically trained on the work, but these naturally required a great deal of supervision, which on distant parts of the work it was not possible to give. Accidents were consequently frequent, and any accident that could not be repaired on the spot necessitated a stoppage of the machine for several weeks, if not months. There was, during the early part of the project, a disposition to keep down the pay of fitters and drivers, which had a very unfortunate result; and it was some time before it became apparent that a very highly enhanced pay was necessary to induce even inferior men to live at the Periyár. When this fact was at last established the calibre at once improved, and a few men of knowledge and character were obtained whose services were invaluable; but the average was at all times low. The office of the Superintendent of Plant and Machinery was in consequence one of peculiar difficulty, and the project is very largely indebted to a young, but most talented and energetic officer, Mr. E. R. Logan, for his unfailing resource and unremitting exertions in this post. The plant comprised three steam tugs, an oil-launch, a large and several small dredgers, two complete tunnelling plants, all the workshop machinery, besides a large number of portable engines, pumps, &c., so that the office of Superintendent was very far from being a sinecure.

Materials.

Before resuming the history of construction the materials used and the methods of preparation need a short description.

Stone.

The stone throughout the Travancore hills is a hard syenite, weighing about 180 lb. to the cubic foot. It formed an excellent foundation for the dam, being fairly free from cracks and fissures and remarkably homogeneous. It blasted well and broke up clean and sharp for concrete, but dressed exceedingly badly and was useless for ashlar. The small quantity of this description of work required was done with stone procured ready dressed from Madura. A portion of the stone used in the main dam and left bank extension was procured from the excavation for the right bank escape and the rest from quarries. The rock cropped out in numerous places and there was no difficulty in finding convenient quarries. Boulders were also utilised, the outside scale being removed with pick or chisel. The fractures of the quarried stone were so clean and sharp that washing with a water jet was unneeded, but with stone broken in machines for concrete precautions were taken to get rid of the dust. All stone was of course wetted before use.

Lime.

The lime used was obtained from nodular kunkur excavated from quarries near Kuruvanúth, at the foot of the ghaut on the Madura side. An analysis of random specimens is as follows:—

—	No. 1.	No. 2.	No. 3.	No. 4.
Moisture, &c., P.C.	2·050	1·250	1·700	1·300
Sand and silica, P.C.	32·752	22·550	20·500	25·100
Ferric oxide, P.C.	2·400	2·400	2·600	2·000
Alumina, P.C.	1·200	1·400	0·200	2·400
Carbonic acid, P.C.	23·950	29·650	29·250	31·750
Sulphuric acid, P.C.	Traces.	Traces.	Traces.	Traces.
Lime, P.C.	24·200	40·096	42·400	35·000
Magnesia, P.C.	11·460	1·153	1·586	1·713
Loss and unaccounted for P.C. ...	1·790	1·701	1·764	0·740
Total ...	100·000	100·000	100·200	100·000

In 1887, previous to the commencement of work, experiments on the strength and setting of this lime were conducted at Kuruvanúth, but the record of them has been lost. They were, however, satisfactory. The absence, at that time, of a testing laboratory at Madras prevented accurate and detailed tests being conducted in a scientific manner, but on the dam specimens of lime and mortar from every mortar mill, and of lime as issued from the storesheds, were every day preserved and crushed after setting for various periods. The manipulation was too rough to render the figures of historical value, the object being merely to make sure that the lime had not perished or deteriorated. The results were, however, remarkably uniform and satisfactory and no cases of decomposition or premature hydration occurred. The pure lime showed a slight tendency to crack if allowed to set in the sun without sprinkling, but this was only to be expected. Another satisfactory test was the constant submergence and scouring action to which the concrete and rubble masonry were exposed during construction. From this trial the mortar emerged unharmed, except in the rarest cases where it was quite green, and even then the damage was wonderfully slight on all occasions when an eddy was not set up. The progress of the dam was always arranged so as to escape the formation of eddies in the event of a flood, but they could not invariably be avoided, and their violence may be surmised from the fact of hard rough stones of over half a cubic foot being caught up in them and worn smooth and round in a few hours. Where the masonry had had a few days to set and there was no hollow or protuberance for the current to catch, absolutely no damage was done.

The lime was burnt either in intermittent kilns of clay, or in large continuous kilns of stone in clay with an outside casing of stone in mortar. The former were not so economical as the latter, and were only used on emergency. The fuel used was charcoal in equal volumes with the limestone. The lime was slaked on a prepared surface close to the kilns immediately it was drawn, and was then stored in thatched sheds, and used generally between one and three months after burning. Figures of the outturn of the kilns need not be given, since it varied very greatly with the quantity of rain and the direction and force of the wind. After slaking a large amount of clinker remained, some of which was reburnt and some used for floors, latrines, &c. The measurement of slaked lime was generally 1¼ times that of limestone.

Surki.

This was prepared in the usual manner of tiles about an inch thick and four inches square, slightly under-burnt in small clay kilns. The tiles or 'bats' were moulded by hand of selected soil, free from vegetable mould, tempered by watering and treading, and were dried in the sun. The soil contained rather a large number of quartz crystals, being the residue of decomposed rock, but judged by the test of experience it made exceedingly good surki. The quantity of alumina contained in the soil was by analysis about 25 per cent.

Sand.

A very good quality of sand was obtained from the river-bed. The river ran in a series of pools divided by rapids, and in the pools were deposited beds of sand of a limited thickness over-lying the rock. While the lake was still low it was an easy matter to dig up the sand by hand in shallow water or dredge it by small hand cranes mounted on barges, but as the lake deepened the lead became very great, and as it took a long time to fill a boat by hand the flotilla would have had to be enormously increased had the same methods been continued. Accordingly a Priestman's Grab Dredger was purchased and used from a barge. This dredger was capable according to the makers' price list of dredging 400 tons per day of ten hours, but under the unfavourable conditions that prevailed it did not turn out at the best more than 100 tons a day, or 150 tons in a day and a night. The depth of water was sometimes considerable, since it was advisable to exhaust the beds near the dam before going higher up the river. The sand beds were also of varying thickness and a full bucket could not be depended on, while delays were of frequent occurrence on account of the grab catching trees and boulders and being unable to close. Owing to the poor calibre of the drivers available the dredger was of course not worked to its best capacity and break-downs were of frequent occurrence, and in order to supplement the supply another dredger was contrived on the works by utilizing the gear of a large steam-derrick and fitting it to a short jib. The revolving motion of the gear was very slow, and it was found easier to move the hopper barges than to swing the jib, which added somewhat to the expense, but otherwise this made a reliable dredger and was often of great assistance. Throughout the work the supply of sand only just kept pace with the demand, and had it not been for the cessation of building from the middle of April to the end of June more dredging plant must have been provided, but as affairs stood a stock was always laid in during these months that supplemented deficiencies during the working months. The lead eventually reached 9 miles as the lake deepened, and a powerful steam-tug was only just sufficient to tow the barges up and down fast enough.

Mortar.

The mortar was composed of three parts by volume of sand, two of lime, and one of surki. This combination was found by experiment to be as good as any other and the most economical. The mortar was mixed in pan-mills, engine driven, or in country bullock-mills. The former had the better appearance and was the better to work, but as far as could be ascertained there was no appreciable difference in strength or setting. The pan or trench having been cleaned the surki in bats was first thrown in and partially broken up, a little water being then added and the mill revolved until the powder was fairly fine. Lime was then added by degrees and more water until a rather sloppy mortar was formed and thoroughly mixed and ground. Sand was then gradually poured in dry, a little water being occasionally added when the friction became too great for the engine, until the whole was thoroughly mixed and of the proper plasticity. Throughout the work very dry mortar was used, only just dry enough to be worked with a trowel, it being believed that an excess of water forces the mortar to the top in ramming and in evaporation leaves hollows. Experiments to ascertain the minimum necessary for complete hydration were of course made. A maistry supervised each mill and regulated the proportion, but to ensure uniformity the quantities of each material for every charge were stacked alongside the mill in iron basins before mixing was begun. Mortar when conveyed to the work was inspected for plasticity and homogeneity before use by the officer in charge.

Concrete and rubble masonry.

Concrete is not popular as a material to prevent the percolation of water, and it was at first intended to plaster the upstream face of the dam. This intention was dependent on the river being below the work as it advanced and on the possibility of using wooden frames as an abutment for ramming. The abandonment of the low level escape culverts necessitated a reconsideration of this method, and a wall of rubble in mortar, uncoursed, was substituted. It would have been difficult under the circumstances, sometimes impossible, to plaster this wall, even if it were necessary; but the rubble masonry, well pointed, forms nearly as impermeable a skin as plaster. No attempt was made (indeed the expense would have been prohibitive), to ram the joints in the manner followed, for instance, at Vyrnwy, but they were well raked out while soft and afterwards carefully pointed with neat cement up to the 120 level, and above that with specially ground surki mortar; and this, if not interrupted for a short time while setting, was found to be an excellent and very fairly impervious face. The wall itself was rather more than a skin wall, since sudden rises of the river and the advantage of working without interruption obliged it to be sometimes both high and strong. The danger of unequal settlement of the rubble masonry and the concrete was of course considered, but this was held to be imperceptible in a structure built up so slowly as the Periyár Dam. To guard against it as far as possible the front wall was furnished with large buttresses and protuberances, both vertical and horizontal, and particular care was taken with the joint between the concrete and the masonry. Settlement was thus reduced to a minimum and any stresses set up could easily be absorbed.

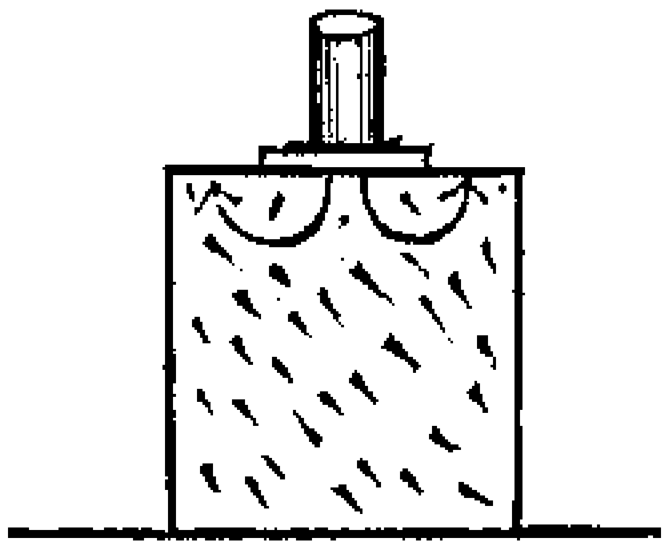
Some careful experiments were carried out in the year 1887 by Mr. G. T. Walch, then Superintending Engineer, I Circle, with the object of arriving at some definite measure of the permeability of ordinary concrete under a great head of water, but the results were not altogether conclusive. The materials employed were Gódávari sandstone and surki mortar as used habitually in the delta, and time ranging from 110 to 150 days was allowed for setting before trial. In the various experiments stone was broken to pass through either a 3-inch or a 2-inch ring, the mortar was composed of two parts by volume of sand, 1 lime, $\frac{1}{2}$ surki, and the proportions of stone to mortar were $3\frac{1}{4}$ to 1, 3 to 1, $2\frac{3}{4}$ to 1, and 2 to 1. The blocks were sometimes plastered, sometimes unplastered, and a pressure rising to 110 lb. on the square inch was applied through a hydraulic boiler-testing force pump, the flange of the pipe being connected to an iron plate with cotton packing, a leather washer being between the plate and the concrete block. The concrete was rammed in 1-foot layers in boxes $2\frac{1}{2}' \times 2\frac{1}{2}' \times 4\frac{1}{2}'$. Pressure was applied on a vertical face or faces, in the direction of the plane of the layers. Mr. Walch's remarks on the experiments were as follows:—

Remarks.

"The plastering was done with the same mortar used in the concrete, but this was not good enough, and, having too much sand, dried (though it was kept wet for many days) with numerous very fine cracks on its surface so that it was difficult, and in many cases impossible, to get an area of surface for applying the water pressure without such cracks. This accounts for the varying results in experiments on plastered faces.

"The results however show clearly, I consider, that concrete faced with good plaster will *not* leak under a head of 135 feet of water. What would be the case without such plastering the experiments do not conclusively show.

"It is quite impossible with such coarse concrete to get a face to it, as it is rammed, smooth enough to take any washer that will make a water-tight joint, and therefore such a surface has to be obtained by chiselling and rubbing, which operations disturb and crack to some extent the mortar round the stones, and then the water entering at such cracks has only a small thickness of mortar to resist it in forcing its way back to the pressure face round the washer. It was so the leakage always broke out; in many cases it also broke out at some distance away and in one case it made its way right through the 2′ 6″ thickness of concrete. Of course in a reservoir dam the leakage back through face would not take place, and I do not believe it would be serious through good concrete of a thickness necessary to give stability; but at the same time I do not believe that even such a mass would be absolutely free from leakage or 'sweating,' unless faced with good dense plaster.



"As regards size of stone, and proportions of stone and mortar, the experiments give nothing conclusive. The blocks of smaller sized stone looked better on their faces than those made of the bigger stone, but it would certainly not in a large mass be necessary to make the whole hearting of small stone. Such stone should, however, be used towards the faces, especially the one to be plastered and to take the water pressure."

A similar experiment was made at the Periyár with concrete rammed in 6-inch layers exactly in the manner and with the materials employed on the works. The pipe was, however, embedded in the concrete, the outer surface of the pipe being previously well plastered; and the pressure was also applied at right angles to the plane of the layers instead of parallel to it. The result was that with 75 lb. on the square inch water began to sweat between the two layers nearest to the mouth of the pipe, and with 10 lb. more pressure a distinct stream appeared.

Speaking generally it may be said, on the occasions during the progress of the work when concrete was directly opposed to a head of water without intervening plaster, that it was not found by any means impervious. A leak which succeeded in penetrating the thick skin of uncoursed rubble masonry found little difficulty in traversing the concrete behind. Such leaks had to be suppressed at the front. If treated in the concrete they broke out in another place, and the few that were allowed to continue were not interfered with, but were conducted to the downstream face and allowed to flow freely out. It is very difficult, though undoubtedly possible, to make a concrete that shall be impervious to a powerful head of water. The expense attending such an attempt on the Periyár Dam would have been totally disproportionate to the benefit attained.

As a matter of subsidiary interest it may be noticed that in Mr. Walch's trials—

Gauge.	Cubic feet. Stone.	Cubic feet. Mortar.		Cubic feet in finished block.
3″	27·72	9·24	rammed down to	25·00
	27·72	8·30	,,	25·00
	27·72	11·08	,,	25·00
	27·72	10·07	,,	25·00
2½″	27·72	9·24	,,	25·00
	30·03	9·24	,,	26·56
	23·10	9·24	,,	21·65
	25·41	9·24	,,	22·37

The deduction is that the interstices in stone broken to these gauges and unpacked constitute more than one-third of the total bulk. Of course the greater part of the stone was much smaller than the gauge through which it is passed. At the Periyár many experiments to ascertain the volume of interstices were made, and it was found that with stone broken to a 2½″ gauge, taken at random from a heap, and packed by hand in a box, the interstices averaged over 40 per cent. On the works stone was dumped by coolies into boxes 5′ × 5′ × ½′, and mortar into boxes 2′ × 2′ × 1′. These when mixed, laid in situ, and rammed, diminished by very nearly one-fifth of the volume of the mixture unrammed.

A certain number of blocks of concrete, 1′ cube, were made on the works and subjected to pressure after setting from one to six months. Experiments with such young blocks are never satisfactory, as they are unable to resist the rubbing and chiselling necessary to enable them to take the pressure plate evenly. Unsupported cubes of small size are also prone to crack at the corners before the material is really crushed. The blocks in this case were made principally to make sure of the adhesion of the mortar to the stone, to inspect the condition of the interior after setting, and to arrive at the weight of the concrete. They gave, however, very satisfactory compression results, the block generally beginning to disintegrate with a pressure of from 40 to 50 tons on the square foot. It will be useful some years hence to cut blocks from the interior of the dam and subject them to comprehensive tests. The average weight of concrete used on the dam was very nearly 150 lb. to the cubic foot.

Timber and fuel.

The country in the vicinity of the dam was in great part clothed with dense forest and at first sight the supply of timber appeared inexhaustible. This, however, was by no means the case. A considerable portion, and that in the most convenient situation along the banks of the river, had been felled and the land used for cultivation by the hill people, and afterwards abandoned. Such land is soon re-covered with jungle, but the after-growth is mostly eeta, and contains no useful trees. In the rest the under-growth was very dense and checked the growth of timber trees, which were besides too close together, so that really useful timber was comparatively scarce. The demand was large, since there were the lime-kilns to be supplied with charcoal, three steamers, a steam tunnelling-plant, and numerous boilers and portable engines to be provided with firewood. Consequently the price for stacking and carriage, which was at first small, increased rapidly and eventually became as great as in places where the wood itself has also to be bought. At the Periyár timber *bonâ fide* required for the works was included in the lease of the land. Throughout the work unseasoned timber was unavoidably employed and was the cause of constant inconvenience. The principal trees used were teak, *Tectona grandis* for all purposes, blackwood, *Dalbergia latifolia* where a very hard wood was required, *Terminalia paniculata*, the common tree of those parts, used for everything and bad for all, *Terminalia chebula* (Gall-nut) for firewood, *Terminalia tomentosa*, for timber, *Anogeissus latifolia* for firewood, *Artocarpus hirsuta* (Angeli), for many purposes but chiefly boat-building. It is lighter than teak and makes a very good boat for quasi-temporary purposes. *Dysoxylum malabaricum* (white cedar) for planks, *Cedrella toona*, (red cedar) for planks, *Sterculia fœtida* (poon) for long spars, derricks, &c., *Lagerstrœmia microcarpa* (venteak) for shingles and firewood, *Phyllanthus emblica* (hill gooseberry), an excellent firewood, but small, *Anthistiria cymbaria*, the common grass of these hills, for thatching, *Ochlandra rhedii* (eeta) for cooly lines.

Main Workshed.

The river, after passing round the right flank of the dam or through the culverts that were built at the higher levels, flowed back into the bed over a weir with its crest at + 24 built originally of piers and shutters, which were constantly destroyed, and therefore eventually replaced by a solid wall. At the downstream or western end of this weir the main workshed was built, running east and west. The weir was far too short and in times of flood the workshed ran considerable risk and was occasionally damaged. At the eastern end of the shed was the motive power, a vertical turbine of 180 H.P. on a 25-feet head. The shed was in two stories, the lower floor being at + 27, and the upper at + 43. It was built of uncoursed rubble in mortar on rock or heavy boulder foundation, but the vibration was so great that all the machines in the upper story were eventually mounted on vertical timbers based on the lower floor, strongly braced, and not touching the walls. On the upper floor was, first, the main shafting, driven direct from the turbine by a vertical shaft and bevel wheels. Opposite the shafting were, at each end, Baxter's stone-breakers, with 14″ × 7½″ aperture, six in all, driven direct by belts, and between the two batteries of stone-breakers two disintegrators for lime and two for surki, driven by belts from countershafting on the lower floor. In front of each battery of stone-breakers was a conveyor for the broken stone, at first of the spiral type, after constant breakages replaced by belt conveyors. These conveyors deposited into measuring drums just below the upper floor. The lime and surki disintegrators fed into measuring drums below the upper floor and thence into spiral conveyors. Sand was fed direct into measuring drums from shoots on the upper floor. The stone-breakers were fed from a platform below the roof and extending outside the shed on the northern side, the stone being deposited on the platform by trucks from the quarries. The lime and surki were fed into the disintegrators through holes in the roof. The lime, surki and sand conveyors supplied two mortar mixers mounted rather high on the ground floor, and these in turn deposited mortar into concrete mixers in a pit in the floor into which stone was fed direct from its measuring drums at the same time. A pump driven from the main shafting forced water through a line of pipes with taps in suitable positions. From the concrete mixer at the western end the concrete was carried by a conveyor to buckets outside the shed ranged on a rail situated on a platform on the bank of the river. The eastern mixer deposited concrete direct into buckets, which were then raised by a hoist to the upper storey. For carriage to the work an overhead wire ropeway was used, capable of carrying 300 tons per 10 hours day at a speed of 4 miles an hour. The wire was of the endless travelling description, on which the buckets were hung, suitable passes and tipping arrangements being made at the requisite spots, and the empty buckets coming back on the return wire. This ropeway was also driven by belting from the main shafting. A fan, lathe, circular saw, vertical driller, and general joiner completed the equipment. The pump was connected to pipes leading to a reservoir at + 200 on the right bank, which supplied the officers' quarters with water by gravitation.

The erection of this workshed was exposed to many vicissitudes, owing at first to the incapacity of the mechanical engineers employed. The building itself was ready for use by October 1890, but the first mechanical engineer, a good fitter but a man with no control over himself or others, had by that time proved his incapacity and was dismissed. His temporary substitute, an ex-engineer of a small steamer, shortly afterwards died of drinking kerosine oil, the only substitute he could procure for spirits. An Assistant Engineer of the permanent staff was then put in charge but was invalided before much could be done, and it was with great difficulty in the intervals of other work that the turbine was at last fitted up, with unseasoned timber under the bed-plates whch afterwards gave great trouble by warping. An Assistant Engineer from the Public Works Shops in Madras was then sent up, and fitted and aligned the main shafting, but he too was shortly invalided. A permanent incumbent of ability and energy was then at last secured, and from that time progress was rapid and difficulties were speedily overcome. These difficulties, however, were abundant and after a full and patient trial a re-organisation was decided on. The following serious defects were discovered. The men feeding unslaked lime and surki from the roof suffered from the dust. They were obliged to work with mouths and nostrils covered and were subject to severe internal pains, so that at last they came to work but three times a week and high pay was needed to secure the necessary hands. Inside the shed it was found that the disintegrators were far from dust-proof, in spite of special joints and other devices, and the unslaked lime and surki combined with dust from the stone-breakers rendered the atmosphere, even with the fan, almost unbearable for any length of time. The apertures of the stone-breakers were too small, stone had to be specially broken to fit them, jams and stoppages were frequent, and the outturn was far below requirements. *The spiral conveyors for broken stone have already been alluded to. These were utterly unfit for the purpose. The spiral conveyors worked well with lime and surki, but in the moist atmosphere of the Periyár the lime set hard along the inside of the conveyor trough and had to be removed nightly with chisels, or a breakage of the spiral was the result. The measuring drums driven off the main shafting were found unsuitable, since they tipped at the same speed whether they were full or empty, and drums worked by hand were too expensive and depended on the regularity of the man in charge, a most uncertain factor—consequently the proportions of the various materials that passed into the mortar and concrete mixers were most unequal, and the concrete was often so visibly bad as to necessitate instant rejection, while no absolute dependence could at any time be placed on it. Finally, the uniform outturn was entirely based on the regular running of all the machines, and the stoppage of any one necessitated the stoppage of the whole of that side, while anything like a breakdown required a complete re-arrangement of the drums. These drawbacks could in time have been overcome, but the space available was far too confined to afford proper room for feeding bins above and hopper reservoirs below the machines, and meanwhile the dam was being seriously delayed at a period when time was of the greatest consequence. After due consideration the concrete and mortar mixers and disintegrators were entirely cut out, and mortar was mixed in mills worked by engines or bullocks in convenient places and conveyed separately to the work. The stone-breakers were retained and the stone conveyed direct to the ropeway and thence to the dam. The concrete was mixed in situ by hand.

Until the workshed was ready for use the stone-breakers were driven by steam on the right bank escape, but even then, and much more later on as the work progressed more rapidly, it was seen that the outturn was insufficient. When the stone-breakers were all removed to the workshed two others, with aperture 20″ × 12″, were procured and driven by portable engines in the open air on the escapes. These had plenty of room and were fed more easily and could be run at night, while the size of the aperture rendered jamming far less frequent; so that the outturn of these two was in reality greater than that of the other six, and they were in consequence considerably cheaper. Their proximity to the quarry and the wide area of storage room around them enabled the contractor to supply stone direct from the blasting without previous stacking. This was in itself a great economy. Being situated on the escape at a level of + 144 they commanded practically the whole of the dam, and broken stone from them was run to shoots and shot straight down to the work-spots. This was an enormous advantage. The main workshed being at a low level and the quarries high, the unbroken stone had to be run down an incline on which the full trucks pulled up the empty ones. While the dam was low this was no great drawback, but as the work rose the broken stone had to be delivered up-hill. In case of a stoppage on the ropeway, which often occurred from broken strands or a resplice, the delay was very aggravating. In such cases coolies carried the stone up in sacks, but the expense and confusion were excessive.

Canal.

For conveyance of materials between the top of the ghaut and the main dam there were several possible arrangements. The first, and that proposed in submitting the estimates, was a metalled road, on which it was intended to run traction engines. The second was a similar road, but shorter and with heavier gradients, without traction engines, materials being carried by ordinary carts. The third was a narrow gauge railway. The fourth was an overhead wire-ropeway. The fifth was the canalisation of the Mulya Panján, the small river having its head near Tékadi and running into the Periyár about a mile above the dam.

The first and third methods would have been of very similar construction. They would have needed careful alignment, easy curves and gradients, solid and fairly permanent bridges and culverts, and a good deal of viaduct work and blasting, though in all these particulars the traction engines would have had a certain advantage. Both would have required careful and expensive maintenance, a very heavy item in the climate of these hills, and both would have been entirely dislocated in case of serious damage to any part. The first cost, both of way and rolling stock, would have been high, and the amount of firewood used would have caused a marked rise of price in that article and have necessitated well-organised arrangements for a steady supply of dry wood.

The traction engines would have had an advantage in a consideration which was not felt till some time after the works were commenced, namely, the indispensability of a road for carts whatever other method of conveyance of materials was employed It might be held that a road would be unnecessary with a railway in operation, but this is very doubtful. Any breakdown of the railway lasting more than a few hours would have caused intolerable inconvenience in the absence of a road; but under any circumstances a road would have been essential during the construction of the railway, which judging from experience in other matters would have been by no means an insignificant period. A road having been once made the cost of up-keep only would be saved by abandoning it as soon as the railway was finished.

The use of a metalled road and common carts would have been easy and certain, but slow and expensive. The advantage of this method would have been its simplicity and elasticity and the absence of uncertainty concerning costs and rates. As a matter of fact a great deal of the limestone used and all the grain, supplies, bazaar requisites, and private property and merchandise were actually carried to the works on carts by the road, but the cost was very great, and even if the works did not pay directly, they paid in the long run. The cost would have been somewhat less had the road been better, but a large outlay either on first cost or maintenance was unadvisable, in view of the small normal traffic and of the fact that parts were certain to be submerged as the water rose in the lake. If the originally proposed method of passing the water of the river during the construction of the dam had been adhered to, and if the level of the lake had been thereby maintained uniformly low throughout, it might have been worth while to make and maintain a broad first-class road. This consideration, however, applies both to the railway and the traction engines as well as to the road alone. All must have been built at a high level, where the contours were much longer than near the bottom of the valley. The distance would have been great and the bridges and viaducts very heavy. A reasonably easy trace for a railway would have worked out to a distance of some 19 miles. A road for traction-engines would not have been more than about 12 miles, but there would still have been heavy rock excavation and bridging. A first-class road for carts would have been little less.

The fourth method, an overhead wire ropeway, was not considered in detail till the canal was nearly finished, and it was found not to be worth while. A ropeway up the ghaut had already been determined on and was constructed. The expense and difficulty of construction were very great, and though this ropeway did excellent work when it was at length got into order, the experience gained did not favour the notion of another and considerably longer installation, chiefly on the grounds of delay and difficulty. It must be remembered, however, that the country between Tekadi and the Periyár was much easier than the ghaut, timber and labour were handier, and the work would have been done much faster and cheaper. This ropeway might have been partly or entirely driven by a turbine at Periyár and the drain of firewood would not have been nearly as large as for a railway or traction-engines. Heavy goods could not have been carried on it and a fairly good road as an auxiliary could not have been dispensed with. Looking at the matter, however, in the light of actual experience, it is not improbable that this would have been on the whole the best way of surmounting the difficulty. It would have been far less liable to damage than a railway or canal, and damage could be much more easily repaired. The alignment would have been shorter and easier than a railway or first-class road, and there would be a great saving in the cost of permanent way, while locomotives and rolling stock would have probably cost more or not less than wire rope and stationary engines, both in first cost and upkeep. It would have been almost independent of weather and would have needed less skilled labour.

From every point of view a canal appeared on *primâ facie* grounds the most suitable of all the methods proposed. A small river, needing little alignment, ran already in the required direction and the total length need not be more than 8 miles. Rock was presumed to be not far from the surface, so that the construction of cheap locks or dams would not be difficult. The materials required were merely stone, mortar and timber, which are cheaper than iron goods and machines and (what was of more importance) could be quickly and easily obtained. Less skilled labour would be needed both for construction and maintenance, and actual carriage would be cheap and of a nature suitable to the genius of the country, being both simple and slow. No re-adjustment of the arrangements would be necessary, since each reach would become merged in the lake as the water rose and the distance would become less instead of greater. Even on the score of first cost, generally a prominent factor in canals, the advantage seemed here to be with water carriage, since little except light masonry works was necessary to form a channel quite good enough for temporary purposes.

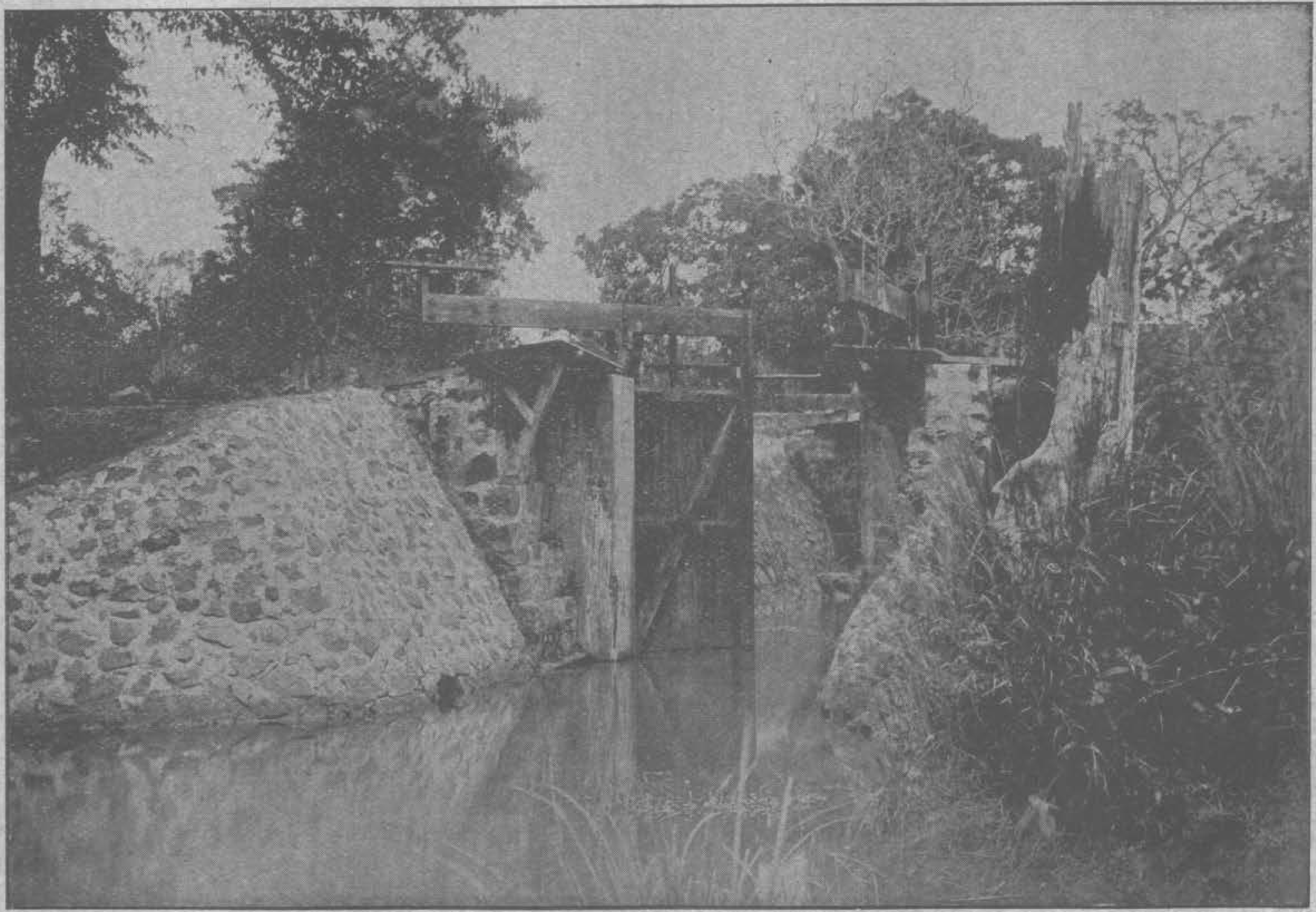


Photo.-Block.

Survey of India Offices, Calcutta, 1899.

LOCK ON MULIAPANAN CANAL.

On all hands, therefore, a canal seemed preferable, and its construction was decided on. The details, difficulties and contretemps will be described as they occurred, but it may be stated here that they were a great deal more frequent and more serious than was anticipated, so much so that at times it seemed as if any other method would have been preferable. It is however doubtful if they would not have been at least as oppressive with a railway or a first-class road with traction-engines, and had either of these courses been adopted, it is at least open to speculation whether a canal would not have at times been more ardently wished for than was ever a railway.

Construction of Canal.

The first operation was the alignment, which was not a matter of serious difficulty, though complicated by the dense jungle on the banks of the stream, which retarded the surveys and interfered greatly with a thorough inspection of the ground. A suitable line was laid out by February 1888, the distance to the mouth of the river being 8 miles and to the dam 9 miles, with eleven locks with an average drop of 8½ feet. A very simple design was adopted and the chambers were small, the most expensive items in the estimate being the gates, which were necessarily substantial owing to the head of water to be retained. The design was similar to that of a second-class lock-gate in the Kistna, with valves in the gate, worked by a rack and pinion. The estimate for each lock was Rs. 4,000 or just double the allowance in the sanctioned estimates. The lift and quoin walls were of concrete, the chamber of earth sloped to 1 in 4 and revetted. Weirs of rubble in mortar 30 feet long were allowed, to pass 500 cubic feet per second, which was taken to be the maximum discharge of the stream, as far as Nataman's valley, below which an increased length was estimated for.

The first two locks were begun at once and by April 1888 were partially finished, and doubts already began to arise whether it was advisable to build the others. The expense was much greater than was anticipated, and worse still the time occupied in construction seemed to portend a quite intolerable delay. These considerations grew stronger as time proceeded, and by August it became obvious that another plan was necessary. Accordingly it was determined to block up No. 2 Lock and convert it into a dam, to substitute three dams for the next eight locks and for the last piece a short line of tramway as far as the point to which the Periyár backed up on account of the temporary dam in front of the main dam. This entailed the expense and delay of transhipping arrangements, but there was no other resource. The foundations at the proposed sites for locks were found to be far less favourable than was expected, the river bed being of permeable shingle or boulders instead of solid rock; nor did the sites admit of much alteration. The dams were fewer and admitted of more elasticity in the choice of site. The cost of the locks was, as already stated, very high, and three dams were certain to be cheaper than eight locks. But the chief difficulty was on the score of labour and supervision. Each lock entailed a separate little camp in the jungle and separate superintendence. Both coolies and skilled labourers were most reluctant to be employed on these works, what with bad lodging, bad water, difficulties in food-supply, and terrors of wild beasts—the latter not by any means altogether imaginary, since elephants had to be constantly driven off with tom toms and firebrands and the night was full of significant sounds. At a later period in the works one man near a wood-cutters' camp was killed by a tiger, and another man mauled in the doorway of his hut in the camp itself. The dams of course entailed the same troubles, but in a minor degree, and were undoubtedly of two evils the less. Their construction was, therefore, briskly pushed on, and the canal as finally decided on became of the form shown in the longitudinal section. Its construction is summarised in the following résumé of the monthly progress reports.

In September 1888 the report of progress stated that elephants had been unusually troublesome, breaking into a shed at No. 2 Dam, and taking out and destroying two barrels of Portland cement (a material for which they had a special weakness), pulling up furlong stones set in concrete along the road, and so on. By the end of February 1889 the dams were completed with the exception of a few days' work at No. 1 and No. 3. During the fever months nothing was done, and in July No. 3 Dam was topped by floods in the Muliya Panján and Nos. 1 and 2 nearly so, in spite of vents left in them for the passage of water, but no damage was done. During the next season earthwork was proceeded with, the waterway cleared of standing and fallen trees, tow-paths formed and arrangements made for navigation. In July 1890 the weir of No. 2 Lock was carried away by trees dashing against it, but the dams were in good order and the transhipping arrangements were commenced, but the unhealthiness of the camps and the lack of

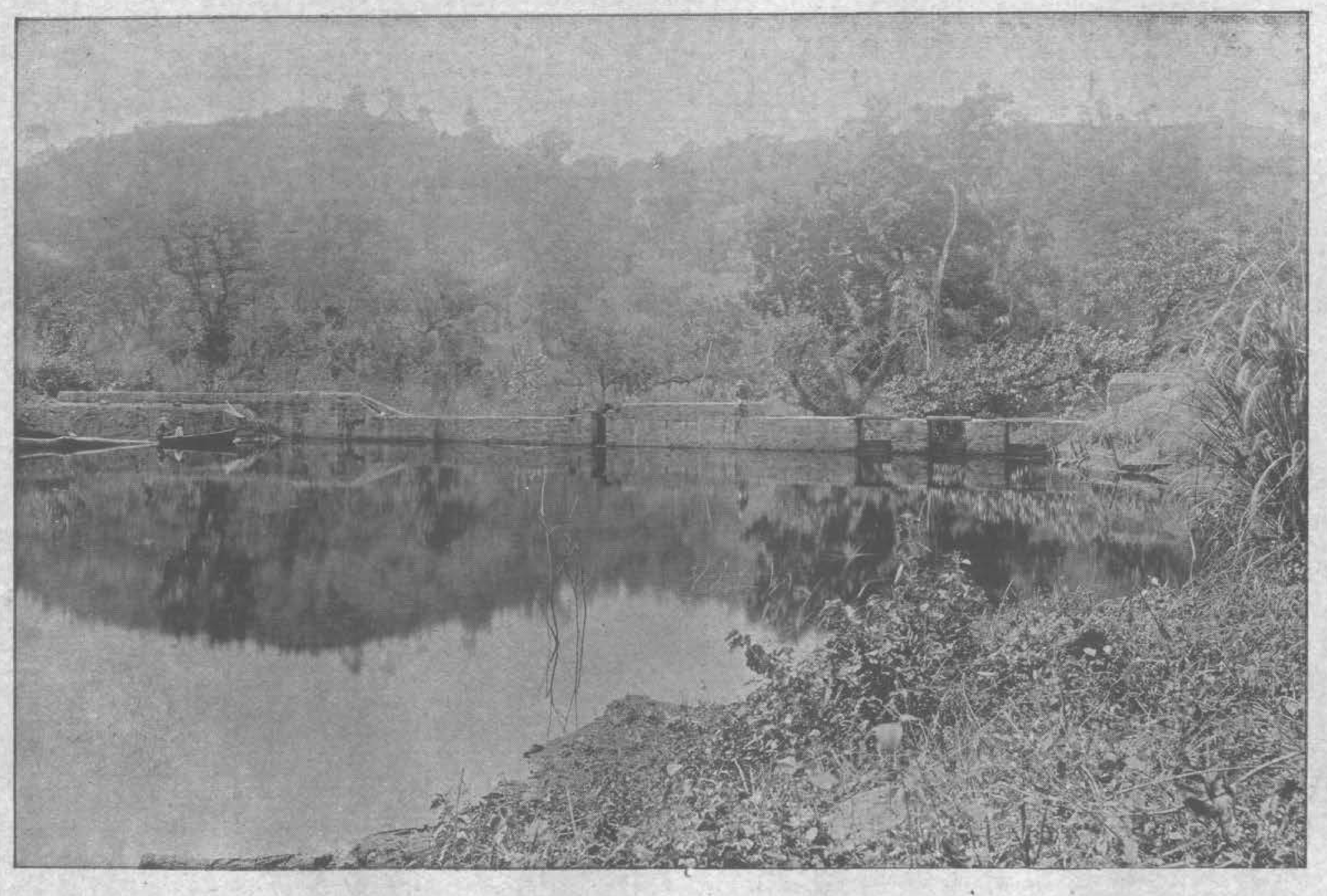


Photo.-Block.

Survey of India Offices, Calcutta, 1899.

MULIAPANJÁN CANAL.

establishment rendered progress slow, the whole of the labour sometimes deserting a piece of work. The unloading arrangements were completed in September, but the re-building of No. 2 Lock weir gave much trouble, and it was not completed till January 1891, by which time a heavy leak had appeared round the flank of No. 2 Dam, which compelled the lowering of the water for inspection and repairs. The canal was, however, now in partial use and it had become evident that for the third reach a steamer for towing was required. This was accordingly purchased from the Tansa Water Works. By the end of March of this year the whole canal was reported ready for use. It was, however, considered unwise to attempt to make the expensive piece of tramway below the last dam, and materials were accordingly unloaded at a wharf between No. 2 and No. 3 Dams and were thence conveyed to the main dam, a distance of about 2 miles by cart. The trouble and expense were, of course, great, but it was considered that by the time the tramway and other arrangements were finished progress on the main dam would have backed the water up to the foot of No. 3 Dam.

In October No. 3 Dam breached, probably from overslaked lime having been used in its construction. The bank between No. 2 Lock and its weir also breached, owing to heavy rain and a flood in the Muliya Panján. The latter damage was quickly repaired and limestone was carted from No. 2 Dam, which was close to the road. By the end of January 1892 No. 3 Dam was rebuilt, but as the first and shallowest reach ran dry during the succeeding month water was not held up against it. Limestone was carted all the way from Tekadi and advantage was taken of the canal being unwatered to carry out certain improvements in transhipment. In July of this year 23½ inches of rain fell including 6·80 inches on the 23rd. The bund of the turbine reservoir breached and aggravated the flood in the Muliya Panján, and No. 3 Dam was undermined and overturned, most of the transhipping arrangements washed away, and several barges sunk. A bund of earth and sand bags was built below the wharf to replace No. 3 Dam and other repairs were completed by October 15, but the bund collapsed within a couple of days, and from that time limestone continued to be carted from No. 2 Dam. Water, however, failed by the end of November, and the canal did not fill again till the following July. From this time reports alternated between "Canal in good order and traffic regular" to "No water in canal." From July to January in each year it generally worked satisfactorily, and as the various dams were gradually submerged by the backing up of the water in the Periyár the supply in the canal had less call upon it.

By July 1895 the water in the Periyár was backed up a height sufficient to allow uninterrupted water carriage from Tekadi to the main dam, and the canal may be said to have then ceased to exist. Its history has been given at some length, with a view to explaining the trouble and expense of which it was itself the subject and which it caused indirectly in the dislocation of traffic when it was supremely important to maintain an uninterrupted supply of material. It will have been seen that the whole of the working seasons of 1889, 1890, and 1891 were occupied in constructing this canal and during all this time limestone and such other materials as came from the plains were delivered by road. The locks and dams were finished by March 1889, and it was the earthwork, towpaths, clearance of obstructive jungle, and transhipping arrangements that occupied the rest of the time. The jungle-clearing was a most tedious operation, since a track for boats had to be marked out and the trees and undergrowth felled and removed in water. The rise of the water level then rotted other trees which fell in great numbers across the fairway and had to be dislodged piecemeal. All these things could have been done easily in a good climate with plenty of labour and appliances, but the drawbacks of situation already alluded to rendered it a matter demanding the most unremitting exertion.

It may further be pointed out that the canal was never used below the wharf between Dams Nos. 2 and 3, until No. 3 Dam was finally submerged; and a rehandling and cartage of 2 miles was the result. An estimate of rates based on the presumption of cheap water carriage throughout the duration of the work was therefore certain to be much at fault, even had the rest of the canal been in working order the whole time. Of such length of the canal as was habitually used it may be said that it answered its purpose admirably and formed a cheap, easy, and efficient means of transport. Even this was however dependent on two factors, namely, the supply of water to the ropeway up the ghaut and the supply in the canal itself. When the former stopped it was found that it did not pay to cart limestone up the ghaut, ship it at Tékadi, and unload it into carts again at the wharf. When the wire ropeway was not working the canal was, therefore, practically inoperative.

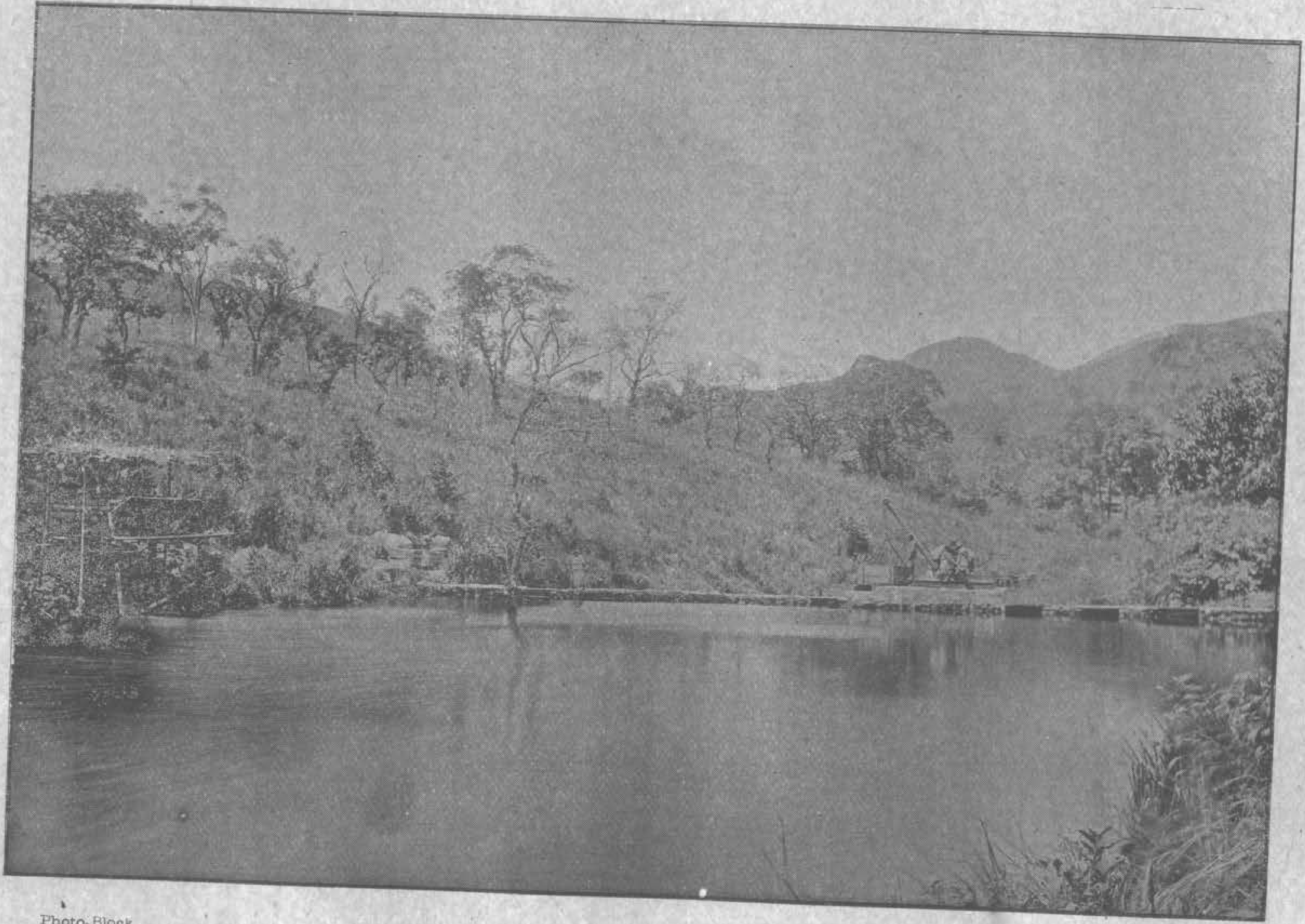


Photo-Block.

Survey of India Offices, Calcutta, 1899.

MULIAPANJÁN CANAL.

At favourable times stocks of limestone were accordingly pushed forward, but at certain seasons of the year the road was always heavily taxed. This is an illustration of one of the defects of water-power or water-carriage when the supply is not unlimited. Fuel can always be obtained in some way or other and steam-power therefore can be readily expanded. Water-power does not possess a corresponding elasticity, though as far as it goes and under favourable conditions it is undoubtedly very cheap.

A word may perhaps be devoted to the transhipping arrangements. The limestone, which was almost the only article carried, was loaded in opening boxes which were first lifted by stationary cranes mounted on the dams, and then placed on frames, mounted on wheels, which were run on rails laid on piers behind the dam to shoots. The boxes being opened the stone ran down the shoots into similar boxes arranged in a boat waiting below. The shoots were swung on pivots to allow for variations in the depth of water. The boats were flat bottomed, of wood, generally 40 feet long by 10 feet wide, and 3 feet deep, carrying a free-board of about 8 inches when fully loaded. They were originally square-ended, but were afterwards all fitted with bows—a great improvement. The conditions of haulage in the various reaches were so various, that it is useless to give particulars of loads carried or distances covered.

The actual cost of the canal was Rs. 1,20,000 excluding maintenance.

Wire Ropeway Transport.

The reasons for determining on this method of transporting material from the foot of the ghaut to the top are fully set forth in pages 25–27.

The report there quoted sets forth the principles of the original scheme for the ropeway, the details of which were but slightly deviated from and then chiefly in details.

The main features in which the ropeway erected differed from that originally planned were—

(*a*) The ropeway was driven by a separate turbine and not by the turbine driving the tunnel air compressors. The water-supply which fed the tunnel turbine, after passing through that turbine, was led by a contour channel half a mile in length to the driving station of the ropeway. The turbine used was a 60-H.P., Girard turbine and the fall available and used was 179 feet.

(*b*) The length of the ropeway was increased from 12,000 to 16,610 feet.

(*c*) The material carried was limestone and a small quantity of surki only, all other materials and stores being transported in country carts.

The form of post recommended by the English contractors for the machinery was a four-legged trestle post of squared scantlings. A trial was given and results showed that were this form adhered to the ropeway would take years to erect. It was accordingly decided to restrict the employment of this form of post to those posts which were upwards of 90 feet in height and to make the others out of single trees or two trees spliced. As the line passed through thick jungle trees of the size required were not hard to find. Elephants were employed to drag them to site and a gang of lascars from the West Coast was employed to erect them.

The great objections to the single tree posts were (1) their liability to twist, (2) their destructibility by white ants, (3) susceptibility to wet and dry rot. To obviate these objections the following steps were taken in each case:—(1) Guys were used but were often stolen by passing coolies and cart-men. (2) Sulphate of copper in solution was put into holes so arranged that the whole area of the post was covered. This met with such a moderate amount of success that it was discontinued on account of the expense. (3) The closest attention was given to the posts to prevent wet or dry rot and the usual remedies employed, with but partial success, as the trees were cut down and used at once without being in any way seasoned.

Results showed that the four-legged trestle post was the better for permanent use, but that considering the length of time required for erection and the expense and the difficulty of obtaining seasoned scantlings, the single post system was the best for temporary use in that particular locality and under the particular circumstances prevailing at the time of erection.

When posts were pulled down owing to dry or wet rot or white ants, they were replaced if very short by three-legged posts of 4″ W. I. pipes, and if over 24′-30′ by a four-legged trestle post of wooden scantlings.

The ropeway was divided into four sections—

A—B	5,660′
B—C	2,700′
C—D	2,050′
D—E	6,300′
	16,600

A being the terminal station at the upper end, and E at the lower end, C being the driving station and an angle, and B and D being two other angles.

The span between the posts never exceeded 300 feet. In stretching the rope, which was done by winches placed on the top of convenient hills, the sag allowed for each span was not less than $\frac{\text{span}^2}{26,000}$.

The first rope used was Bullivant's steel wirerope, Bullivant's lay, the circumference being 2 ⅜ inches. The second rope was the same size but Lang's lay. The rope travelled and the buckets were attached by Carrington's runners and hangers. The weight of the bucket, &c., was 74½ lb. The capacity of the bucket was 1-⅞ cubic feet of limestone and 1 cubic foot of surki bricks.

The speed at which it ran varied from 2½-3 miles per hour.

The first rope worked for 9—10 months and was badly worn after running only three months. No doubt this was in great measure due to the rope having lain in a river bed covered with sand on its way up. The second rope was Lang's lay and worked until the ropeway stopped without signs of appreciable wear.

The lift from station E to C was 1,100 feet.

C-B about 350 feet.

B to A a drop of about 200 feet.

Making the total difference in height between E and A about 1,250 feet.

The quantity of material carried per working day averaged 40 tons. The working day may be said to have been about 7 hours actual running on the average, so the quantity carried per hour exceeded 5 tons. The cost was Rs. 3–4–0 per 5 tons for line lascars, loading and unloading, in addition to which a repairing establishment of 1 carpenter, 1 smith, 1 bellows boy, 4 coolies, 2 boys and 1 driver, was maintained at a cost per working day of Rs. 6–6–0. The cost of small stores was on the average Rs. 2–10–0 per diem, bringing up the daily cost to Rs. 9 or 5 tons per Rs. 1–2–0, so that the actual cost per 5 tons may be taken to have been not less than Rs. 4–6–0.

The best mixture for keeping the rope in order was found to be tar, mica, grease, and oil.

Main Dam.

A description may now be attempted of the work to which all that has been thus far narrated was subsidiary, the construction of the main dam.

After the preliminary proceedings which have been touched on at the beginning of the present chapter, work on the foundation was resumed at the end of June 1888, but little could be done during July and August except earthwork on account of the weather. The following extracts from the Chief Engineer's Report on the foundations describe the conditions and summarise the progress :—

> "The bed of the river at the site of the dam is of rock, sloping very gently for a short distance on each flank and then dropping suddenly, in some places vertically, towards the deep channel in the centre of the bed. This deep channel is from 50 to 80 feet wide and from 12 to 20 feet below the surface of the water when at its lowest, this surface being 2 feet above the datum line of the Periyár surveys. The maximum flood level is about 20 feet above this datum, but the highest flood recorded since the works were begun is 15 feet above it. The existence of this chasm in the river-bed has added greatly to the difficulty and expense of getting in the foundations ; it gradually narrows both above and below the site of the dam, and disappears entirely a short distance in each direction, but the nature of the banks prevents any great deviation from the actual site. When the original designs were prepared the existence of this chasm was not known, and the bed was supposed to be a tolerably smooth rock with its greatest depth not more than 6 feet below the minimum water level, and the scheme of construction described in the original report was based on this supposition. It was intended to construct a temporary dam distinct from the main dam, a short distance above it, to a height of 30 feet above datum, and a similar dam 10 feet high below the main dam, the space between these two dams being pumped out to enable the foundations of the main dam to be put in. The object of making the upper dam 30 feet high was to obtain, as soon as possible, sufficient head of water for working the machinery for the manufacture of the concrete to be used in the construction of the main dam. When the banks were cleared of jungle and the real conditions ascertained, it was evident that the upper temporary dam could not be constructed in the position or by the process originally intended."

The jungle was of the thickest and most impenetrable nature, the undergrowth being composed chiefly of eota (*Ochlandra rhedii*) and rattan creeper, through which lanes had to be cut with axe and chopper in order to take the cross sections of the valley. It was, therefore, very

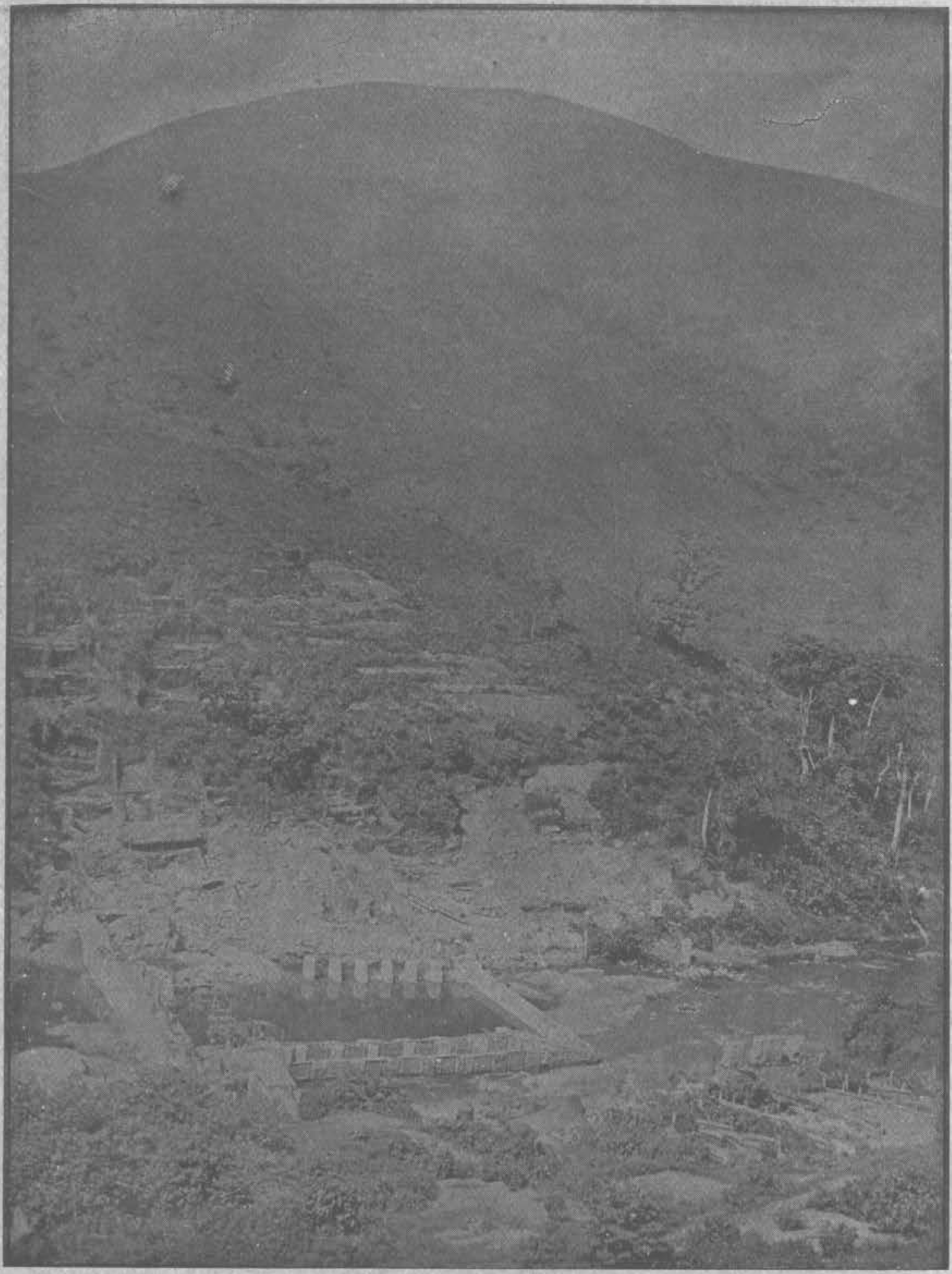


Photo-Block. Survey of India Offices, Calcutta, 1899.

FOUNDATION ENCLOSURE.

difficult to ascertain at a moment's notice the exact conditions of the river-bed at this point. The site, it may be remembered, was suggested last of all, and was selected for other considerations than the exact level of the river-bed. Later on the jungle on the banks was turned to account for hut-building and firewood, so that before the work had proceeded very far the banks for some distance above and below the dam became perfectly bare.

"It was then determined to build this (upper temporary) dam about 200 feet higher up the river, where the central chasm was much narrower, and to lead the ordinary river discharge round the main dam by a channel cut in the earth of the right bank.

"The flank portions which were in no great depth of water were put in without any serious difficulty, though with frequent interruptions from floods, the protective works being carried away again and again. In order to obtain a foundation for the central portion it was determined to fill the central chasm with dry stone up to water level, and to build upon the base thus formed. By the end of February 1889 the flank portions had been built up to + 13 above datum, vents being left for the passage of water until the completion of the dam when it was intended to close them with wooden shutters. The central portion on the dry stone base was up to 10 feet above datum, and the base showed no signs of settlement. It was intended to leave the flanks at + 13 until the central portion was up to + 20 and afterwards always to keep the central portion well above the flanks, so that floods might go over the latter and the rubble base not be disturbed by falling water.

"At the period mentioned freshes of any magnitude are exceedingly rare, and there was every reason to expect that the central portion would be carried up to the height required without interruption. Unfortunately this expectation was not realised; on the night of the 1st March there was heavy rain over the greater part of the river valley and early the following morning the river rose suddenly, the discharge rising from about 300 cubic feet per second to 4,000 in less than an hour. Of course the greater part of this discharge passed over the central portion, the upper part of which was quite fresh, and the green masonry was entirely destroyed. As far as could be seen from very careful observation the rubble base did not yield at all till after the masonry gave way, but of course when the latter was removed and the whole discharge passed over the former, a good deal of the stone was removed by scour.

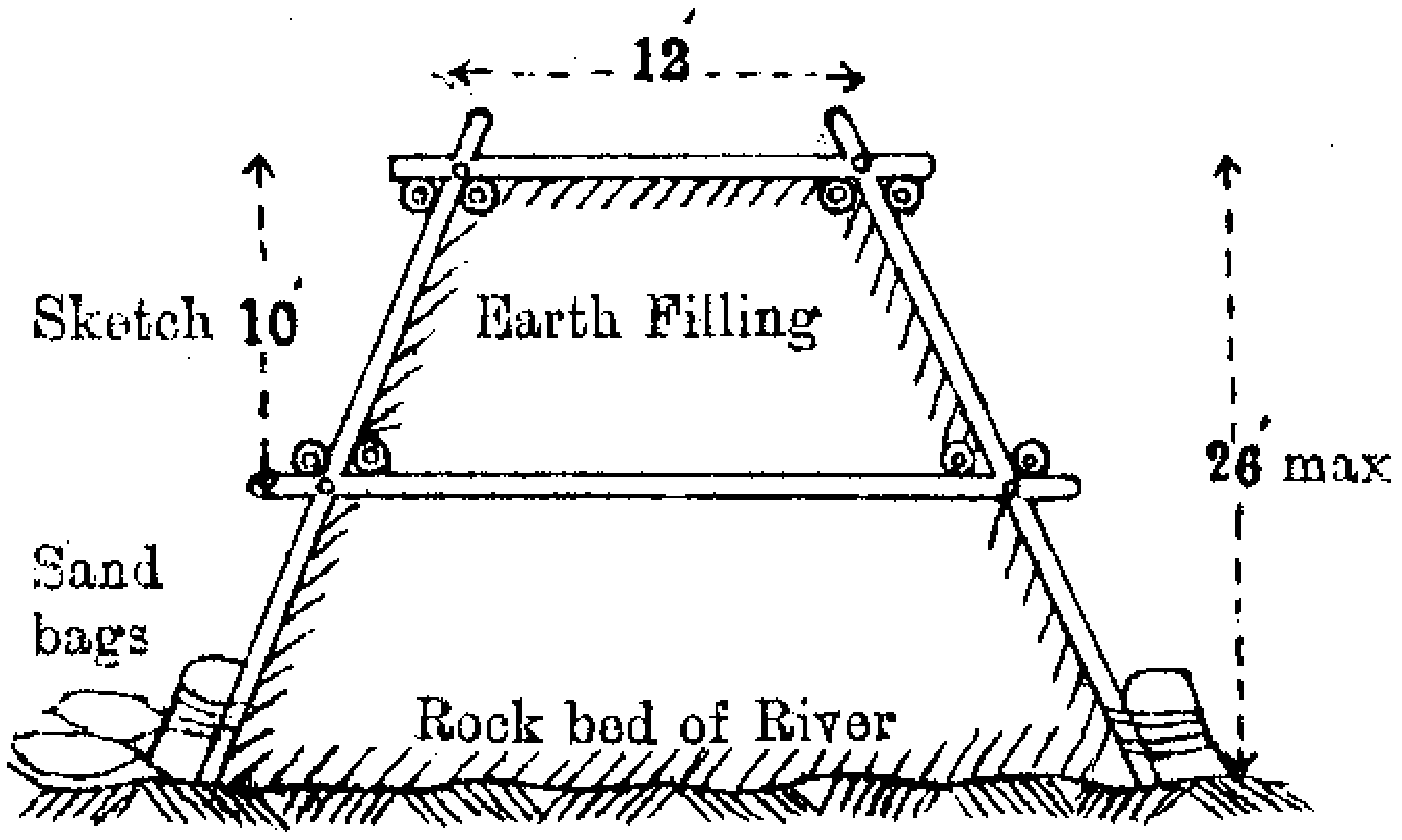
"It was too late in the season to think of restoring the damaged portion on its old lines and it became necessary to consider whether a different arrangement could be adopted. The flood which caused the injury described above was not of long duration and by the 5th March the river had returned to its normal condition. It was then necessary to decide and to decide promptly what change of plan was practicable. To re-build on the former lines meant a whole season's delay; only four weeks more remained during which work was practicable, and it was physically impossible to complete the dam within that period, while any work left unfinished would be infallibly destroyed in June; practically therefore it would be necessary to wait till the following January before anything could be done. It was decided therefore to abandon the idea of constructing a temporary dam separate from the main dam merely to raise water to the height necessary for working the machinery, and simply to enclose the site of the main dam by a coffer-dam of sufficient height to keep out the ordinary cold weather stream. It was recognised that this coffer dam must be of masonry, as except from January to March it was impossible to reckon on a fortnight without a fresh which would carry away an earthen bank.

"The first step was to construct a row of masonry piers (see plan) as close as possible to the right edge of the deep chasm, extending from the temporary dam to a short distance below the rear face of the main dam. These piers were 6 feet apart, 5 feet wide, with their tops at + 13, 3 feet thick at top with their rear faces stepped 1 foot horizontal for 2 feet vertical. It would have been better to have made them somewhat thicker, as the dimensions given left very little margin of stability against sudden shocks (in fact several were afterwards carried away by trees striking against them), but it was feared that if this were done it would not be possible to complete them by the end of March. The portion of the temporary dam between the line of piers and the right bank was removed and the piers continued a little higher up to a point where the central chasm was still narrower and shallower, and the line was then continued down the left side of the chasm to the left portion of the temporary dam.

"It will be seen from the plan that when the spaces between the piers were closed by wooden shutters or other means, and a dam put across the river between the lower end of the line of piers and the left bank, the site of the main dam would be completely enclosed as long as the discharge of the river did not exceed what could be carried by the space between the piers and the right bank (about 2,000 cubic feet per second), and if the coffer-dam were watertight it would only be necessary to pump out the enclosed space to enable the foundations of the main dam to be put in without difficulty. It was, however, certain that the coffer-dam would not be watertight, especially at the upstream end where the closure would have to be made by sand bags, and that the leakage would be more than the pumping power at our disposal could deal with. A second dam was, therefore, necessary above the main dam, to take up this leakage and pass it by a minor byewash on the left flank. It was at first intended to make this byewash with piers and shutters similar to those on the right bank, though not so high, but time did not allow of the completion of the whole of the piers, and for part of the length an earthen bank was substituted, which acted quite satisfactorily. The construction of all the piers shown on the plan was finished by the end of March 1889, when work was suspended till July.

"In most years there is an interval between the two monsoons (from the middle of August till the middle or the end of October) when the river is comparatively low, and it was thought possible that the cross dam might be put down and a portion of the masonry got in during this interval. In 1889 this interval did not exist, the discharge of the river being almost as great in August as in July, and in September and October considerably higher. On the other hand, the north-east monsoon was an entire failure and there was very little rain in November. The intervals between the piers were in that month closed by wooden shutters and the central gap between the upper end of the right and left bank rows was closed by a mass of sand bags. It may be mentioned here that sand bags were very freely used and were found invaluable for closing gaps of all kinds, such as those left by the destruction of piers by floods. In some cases they were put down when the velocity was so great as to carry away the bags like pieces of paper, but there was never any serious difficulty in checking the velocity by wooden trestles and planks under cover of which the bags were deposited. The flood of the 18th December passed 2 feet over the sand bag bank at the upper end of the coffer-dam and did no damage beyond the displacement of a few bags in the rear slope. Towards the end of November it seemed likely that no more floods were to be expected, and the construction of the cross dams was put in hand".

These dams were formed of wooden trestles carrying two rows of sheet piling with a filling of earth, and as these trestles played a prominent part in the operations in the bed of the river they merit a passing description. They were in lengths of about 30 feet and were built on shore. Uprights of lengths suitable to the depth of water were set up at distances of 5 feet apart in the line of the dam, 12 feet apart at top and sloping outwards and downwards with an inclination of 1 in 4. To these uprights were fastened longitudinals at vertical intervals of 10 feet. The longitudinals were doubled, that is, one was fastened before and one behind each upright. Distance pieces were then fixed and the structure was ready for launching. The whole was made of unsquared timber of a maximum diameter of 8 inches.



Careful soundings had previously been taken, so that the requisite length of the verticals both on the upstream and downstream side was known and each trestle was built for a particular position. When all was ready the trestle was launched on a raft and floated into position, where it was sunk by tying on large boulders. Sheet piling was then driven down to the bottom between the longitudinal guides, and thus an enclosed space was formed from which the water could be expelled by a filling of sand bags or loose earth according as the water was running or still. The rocky bottom of the river precluded the use of vertical piles unless of steel. There were no steel piles at hand nor any appliances for driving them—a difficult matter in more than 20 feet of water; while timber trestles could be made up on the spot and put down much more quickly. The usual filling for a coffer-dam of this description is clay; but suitable clay was not available, the earth throughout these hills being either soft vegetable mould or decomposed syenite which stood well when dry but turned to slush in contact with water. A dam of rubble tipped into the river might have been made, but it would have leaked excessively and would have used up a great deal of stone which would have been irrecoverable. Such a dam, made watertight by earth or sand bags in front, would have cost more and taken longer to make, while all the stone readily procurable at the time was required for the rubble in mortar walls to be built inside the coffer-dams.

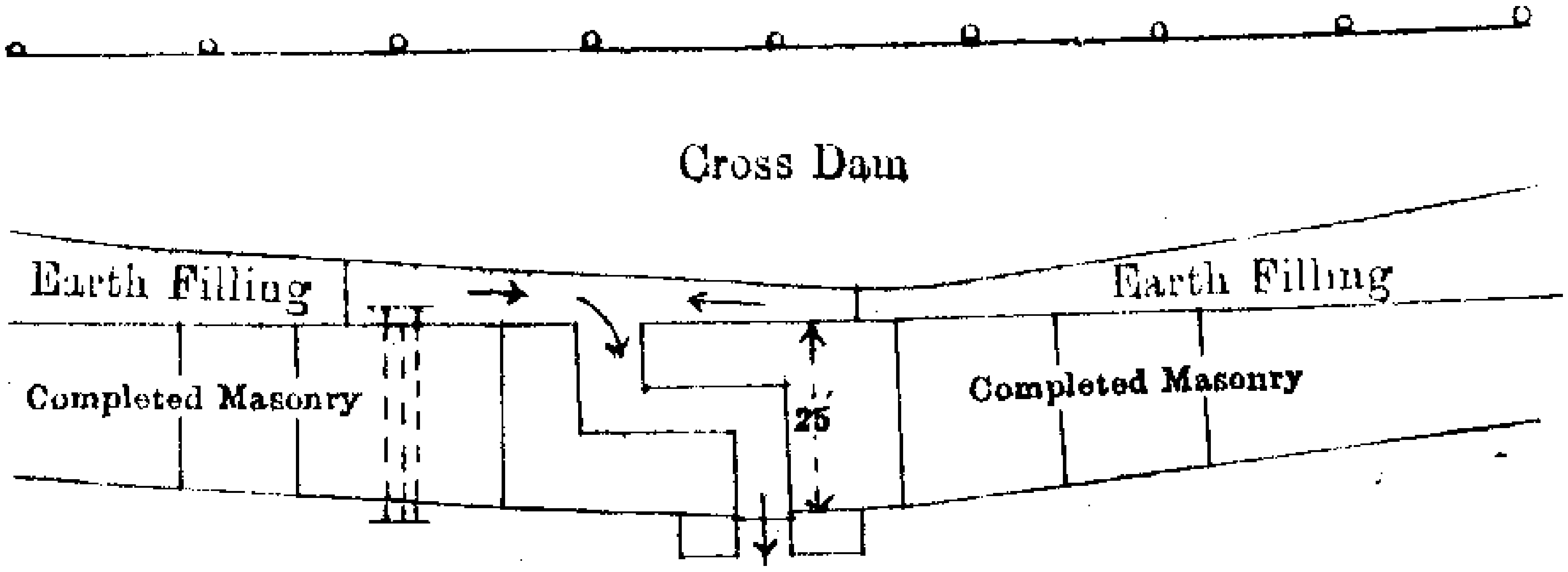
The trestles being put down every energy was directed to enclosing the site of the main dam. Earth was poured into the trestles from both ends day and night. The main stream of course passed by the right byewash, and the only current in the portion of the bed occupied by the cross dams was that due to the leakage (which subsequent measurement proved to be from 25 to 30 cubic feet a second according to the level of the water outside the piers and shutters). Though the water in the pool was thus nearly still there was a slight stream running through the sheet-piling which made the filling a slow business. To defeat the stream various devices were resorted to. Bamboo mats were nailed on the sheet-piling to cover the interstices, sand bags were sunk on the upstream toe to fill the crevices between the ends of the piles and the inequalities of the rocky bottom, and trestles were divided transversely into short lengths by vertical piles resting against the distance pieces. If earth was poured in gradually it went through in the form of muddy water, so large masses were collected at the tips and shovelled in hastily. By this means an abutment was formed at the two ends and the bed was also gradually covered and the filling then progressed quickly till but a short length remained to effect a junction between the two tips. The leakage however had concentrated at this point and the velocity was greatly increased, so much so that there was a difference of level of 1½ feet between the upstream side of the upper cross dam and the downstream side of the lower. The gap was almost filled again and again only to cave in and disappear at the last moment. The difficulty was at length overcome by a liberal use of grass rollers mixed with earth and by dividing the space into small squares by vertical planks and filling each in an instant with a large mass of earth. The crest of the upper cross dam was finished off at + 8, which was considered enough to turn the leakage into the left byewash; and the crest of the lower cross dam was stopped at + 6. This made the upper 26 feet high at the deepest place and the lower 21 feet, the deep bed of the river at these two points being—18 and—15, respectively. It was calculated that the amount of earth used was more than 30 times the contents of the cross dams and the whole site of the main dam, and the space enclosed by the cross dams was covered with slush 6 to 8 feet deep. The cross dams even when finished had to be incessantly watched, and an emergency gang with a large quantity of earth was kept ready day and night to repair the cavities that constantly occurred. Many of the coolies were extremely good at the work, being experienced in it from childhood. A ring of them would form round a cavity pressing close leg to leg and almost excluding or at least breaking the rush of water. They were then buried up to their waists in earth by their comrades, and pulled out by main force, when the operation was repeated until bit by bit the breach was healed. Much of this work took place at night and the exposure in water at a level of 3,000 feet above the sea in December was very trying. The coolies had, therefore, to be encouraged and assisted in every possible way, and had it not been for the medicinal virtues of arrack it is difficult to see how the Periyár Dam would ever have been built. The strain on the staff was of course also very great.

During the operation above described the engine and pump were being placed in position. The engine, a 12-H.P. portable, had to be brought 7 miles from Tekadi along an exceedingly bad road over culverts made chiefly of branches of trees. When it at length arrived it was run out across the right byewash to the edge of the pool, where it was fixed on a timber platform. The pump, an 8-inch centrifugal, was then fixed on another platform over the deep bed of the river and pumping commenced on December, 17th, three days after the cross dams were completed. On the following day there was very heavy rain (3 inches in 4 hours) and during the night the river swelled to a discharge of about 6,000 cubic feet a second. Two of the piers were destroyed and the upper cross dam almost entirely carried away; the lower dam was much less injured than expected, nearly half of it being left almost undamaged; the trestles carrying the pump and pipes were overturned, and the pump buried in the bottom of the river where it remained till it was dug out in April. A still higher flood occurred on December 28th, and it was not until the middle of January that the river was low enough for work to be resumed. A certain delay was however inevitable while wood-work for a fresh set of trestles was being prepared.

On January 12, 1890, the river was again attacked, and time being of the extremest importance the utmost despatch was used. The gap caused by the destruction of the piers above mentioned was closed by sand bags, and the erection of the trestles for the cross dams begun on the 15th. The latter were entirely completed and pumping begun on the 27th. The work was in one way easier, since the chasm in the river bed having been completely filled with mud, most of which remained, there was a mud instead of a rock bottom to work on. But many of the planks, timbers, sand bags, &c., also remained and the trestles were not so easily fixed or the piling rammed so close. In other respect the same difficulties were met as before, but previous experience enabled them to be overcome more quickly. A slight delay was caused by a slip in the lower dam which let the water into the enclosure when nearly dry, but the site was sufficiently clear to enable masonry to be begun on the 30th. It was of course impossible, in the time available, to get in the foundation over the whole area of the dam, even up to normal water level, and it was therefore determined to construct only the front and rear portions (*vide* sections) up to such a level as would be safe from submergence by moderate freshes, leaving the central part to be done in the following season. Of the two walls to be thus constructed the front one was designed for a height of 25 above datum or 43 feet above deep bed, so as to allow the water to be raised as soon as the machinery was ready for work, though it was not expected that it would be completed to this height during the current season. The lower wall was to be 7½ feet about datum, or 22½ feet above the deep bed—a height sufficient to keep out all floods which did not top the front wall.

In order to build the front wall in the most satisfactory manner it would have been necessary to commence at the lowest point, leaving a vent for the leakage to be afterwards closed, and had there been time or room this course would have been followed. But for this purpose it would have been obligatory to wait until all the water had been pumped from the enclosure, slush and débris cleared down to the rock round the pump and along the whole length of the foundation of the wall, and both the upper cross dam and the rest of the slush safely shored up. The time at disposal however admitted of no delay, nor was there sufficient space between the cross dam and the front line of the wall for timbering. As slush and débris were removed the flanks of the site of the wall were first exposed, and they were at once cleaned up and masonry begun. The work was easy at first; but as more slush was removed the leakage became greater and the cross dam threatened to slip and had to be shored up, the timbers being removed and masonry substituted in very small lengths, while the leakage was conducted along the toe round the new masonry to the pump. Had all the slush been removed before any masonry was built the cross dam would certainly have slipped or collapsed. As it was it constantly bulged and the leakage increased daily, and the only alleviation was to fill up at once with rammed earth between the cross dam and each new length of masonry. As the two ends approached each other all the difficulties became accentuated and the bulging and timbering and leakage conduits entrenched so on the site of the wall that it became a matter of the greatest trouble to adhere to the front line, and in fact for a short length in the deepest part the toe of the front wall is nearly a foot behind its proper place. When but 2′ remained to effect a junction the situation became acute. The leakage, which had greatly increased, was pouring through the small space in a rapid stream to the pump. A pipe had been left in the wall a little to the right, but the rock there being higher the pipe was higher and it was found impossible to back up the leakage sufficiently to force much of it through the pipe. The space of 2′ width running through the thickness of the wall was made crooked.

Front of Cross Dam.



and at the back of the wall were built two piers, attached to the wall and forming with it two grooves. In these grooves a shutter 3′ deep was fixed and carefully caulked all round with oakum plastered with clay. It was very nearly watertight and the result was that the running water was raised to the level of the top of the shutter, below that level being still water. Long flexible bolsters made of porous long cloth and filled with neat cement and a few stones were then laid very quickly in the still water up to the top of the shutter, and the pump was immediately stopped and water allowed to rise in the enclosure. With the diminution of head the leakage and the consequent stream of course became much less and the cement had a chance of setting in still or nearly still water. At intervals of three days the water in the enclosure was pumped out and the process repeated, but with cement concrete instead of neat cement. With every rise of the wall the space between it and the cross dam was filled with earth and the leakage diminished until

PLATE NO. V

SURVEY OF THE SITE OF THE MAIN DAM ACROSS THE RIVER PERIYAR.

(IN MAY 1890)

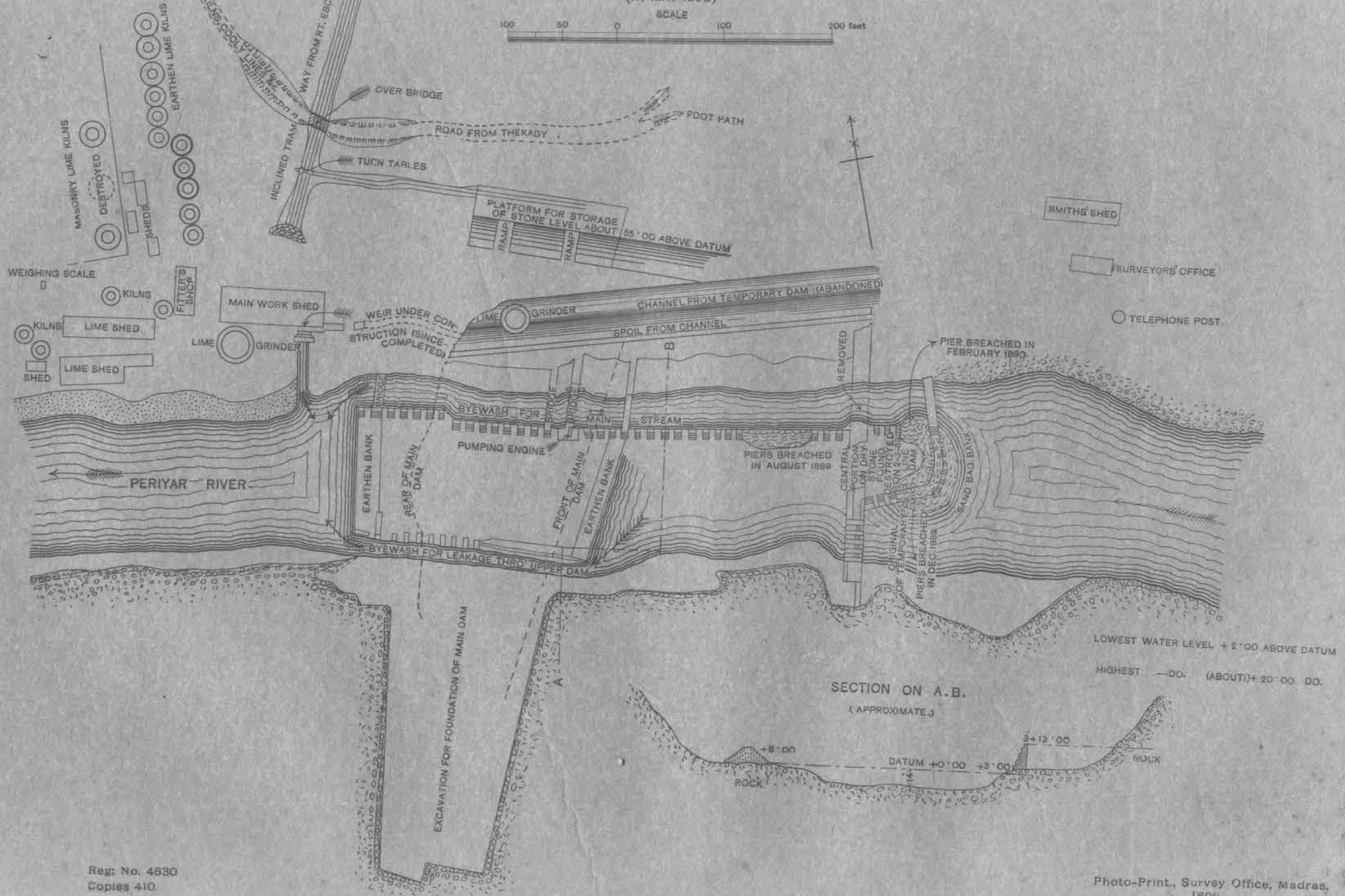


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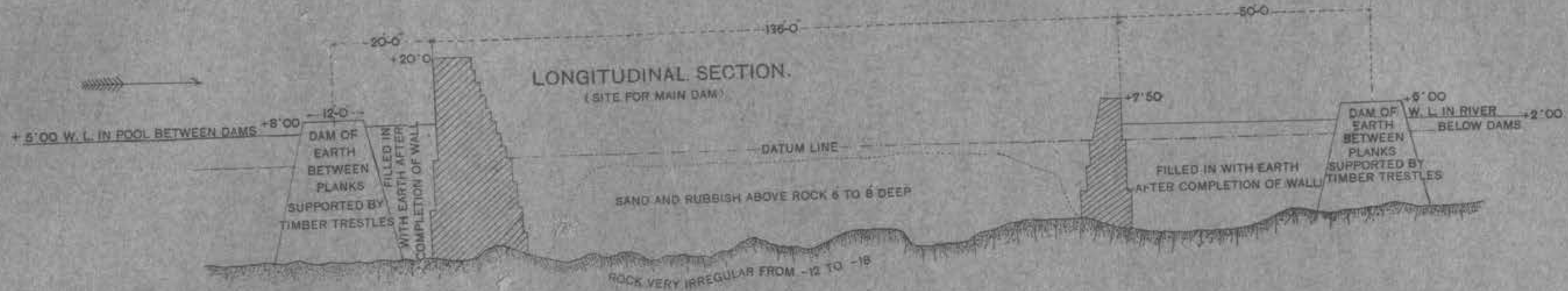
Photo-Print., Survey Office, Madras,
1898

PERIYAR PROJECT WORKS
SECTIONS OF THE MAIN AND TEMPORARY DAMS
ACROSS PERIYAR RIVER.

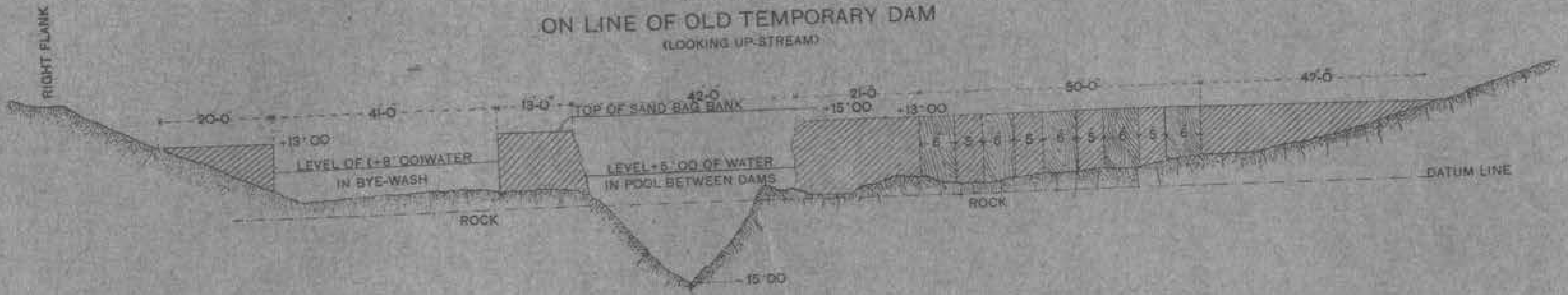
PLATE NO IV

SCALE OF FEET
10 5 0 10 20 30 40 50 Feet

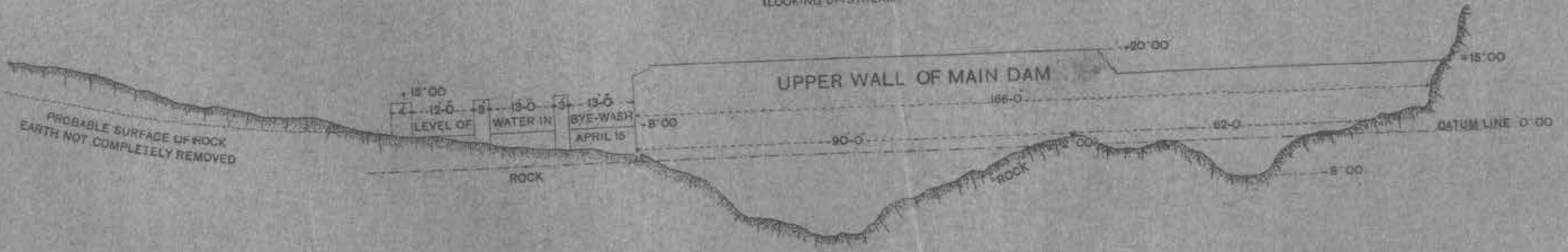
LONGITUDINAL SECTION.
(SITE FOR MAIN DAM)


20-0
136-0
50-0
+20'0
12-0
+8'00
+ 5'00 W. L. IN POOL BETWEEN DAMS
DAM OF EARTH BETWEEN PLANKS SUPPORTED BY TIMBER TRESTLES
FILLED IN WITH EARTH AFTER COMPLETION OF WALL
DATUM LINE
SAND AND RUBBISH ABOVE ROCK 6 TO 8 DEEP
+7'50
FILLED IN WITH EARTH AFTER COMPLETION OF WALL
+5'00
DAM OF EARTH BETWEEN PLANKS SUPPORTED BY TIMBER TRESTLES
W. L. IN RIVER BELOW DAMS
+2'00
ROCK VERY IRREGULAR FROM -12 TO -18

ON LINE OF OLD TEMPORARY DAM
(LOOKING UP-STREAM)



AT UPPER FACE OF MAIN DAM
(LOOKING UP-STREAM)



AT LOWER FACE OF MAIN DAM
(LOOKING UP-STREAM)

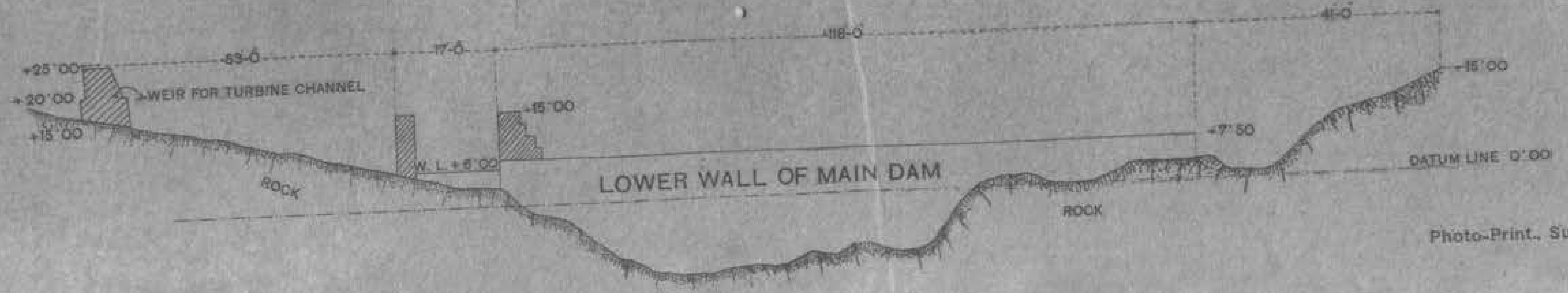


Photo-Print., Survey Office, Madras.
1898

Reg: No. 4629
Copies 410

no special arrangements for building were required. The operation was, however, only partially successful, since a certain amount of water (about $\frac{1}{3}$ cubic foot a second), found its way through the cement bags and the concrete above it. This may be attributed partly to the inherent defects of the contrivance and partly to the extreme haste which was the very first consideration. The success would have been probably more pronounced had the cement and also the concrete been moistened and allowed to set for a few hours before being deposited. Had neat cement in bags been more freely used instead of concrete there would also probably have been less leakage, but the supply of cement was almost at an end and there was no means of getting more.

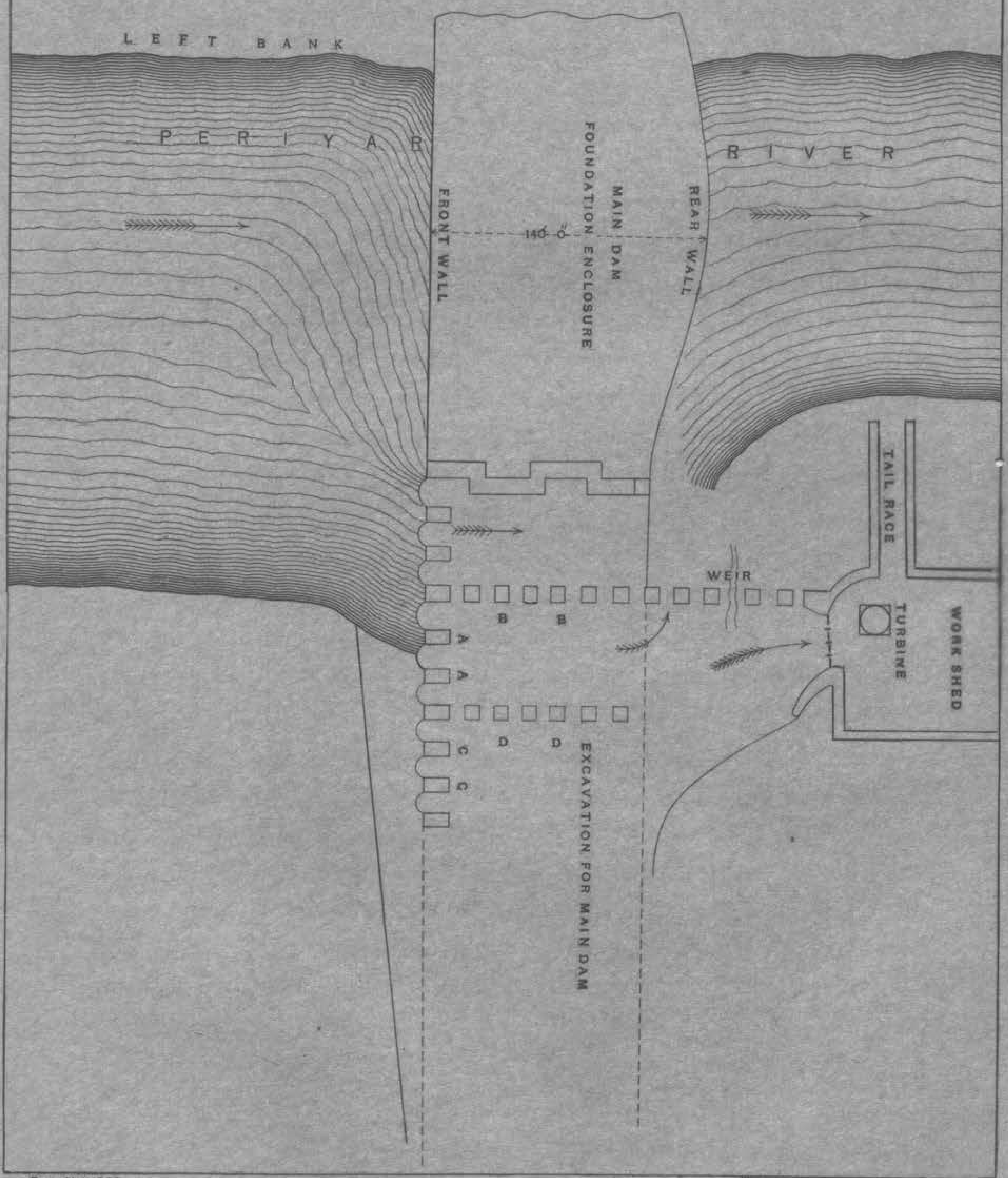
No very great difficulty was experienced in the construction of the lower wall where there was plenty of room to work, the cross dam being 50 feet from the masonry, but in this wall also the foundations of the flanks had to be put in before the centre, and the leakage, though much less in quantity, had to be dealt with in the same manner, since there were no pumps available for disposing of it outside. Consequently this wall also leaked at the base along the deepest part when finished.

"By the 18th February the masonry of the front wall had been carried across the bed but not to the full thickness. On the 24th February the rear wall was just completed and the front wall raised, though not to its full thickness, to a height of about 7 above the datum, except for a length of 40 feet in the middle which was from 6 to 7 feet lower. On that day there was a fresh, not very high but unusual at the time; it would probably have done little or no damage had not one of the line of piers given way, letting the water into the pool above the upper cross dam. The latter was of course topped and breached and the water passed over the masonry. In the upper wall there was space enough for the water to flow over at a very moderate velocity and absolutely no damage was done; in the lower wall the top part, which was quite fresh, was more or less injured, but the damage was on the whole very much less than was expected. The lower cross dam was of course breached but not badly. The restoration of the earthen dams and pumping out the enclosure caused only three days' delay, and work could have been resumed on the 28th, but the weather was so bad and the river so high that little or nothing could be done till the 5th March, after which there were no further interruptions and work went on smoothly. A certain amount of trouble was experienced in extending the front wall across the left bank byewash owing to an unexpected dip in the rock which went down to—8, but this caused no serious difficulty. A vent was left in this portion of the wall for the passage of water into the left byewash, to be closed by a wooden shutter as soon as the masonry was sufficiently advanced.

"It was determined to leave the work for the season with the top of the front wall at 20 above datum, with the exception of a length of 60 feet on the left flank which was to be left at + 16, and by the 15th April this had been done, except the vent itself and a short length on each side which was left to bond in with the masonry used in closing the vent. The shutter was then put down and the vent built up as quickly as possible. This operation was interrupted by a rather heavy flood on the 19th April, which passed over the lower portion of the wall and did some little damage to the newest part of the work; the interruption was particularly annoying at a time when fever was beginning to show itself and there was considerable difficulty in obtaining labour; the work was however finally completed by the 26th April.

"While the front and rear walls were in progress, piers with their crests at + 15 had been built between those of the coffer dam piers on the right bank which came between the two walls, so as to increase the carrying capacity of the main byewash from + 12 to + 15. The dam site is thus enclosed by a solid wall which will not be submerged except on comparatively rare occasions, and the remainder of the foundations can be put in, under cover of this wall, without serious difficulty. There will be occasional interruptions, but they will be interruptions only, and will not involve the destruction of any work already done. When work is resumed next season the front wall will be raised to + 25 and the entrance to the main byewash closed to a sufficient height to cause a sufficient portion of the river water to pass above the weir (which has been completed) leading to the turbine for driving the machinery. The walls described above were not benched into the rock, as time was of the utmost importance; they were founded on the natural surface, which was carefully cleaned, with portland cement; this material was used for the lower 2 feet of the walls throughout their thickness, and for the front 2 feet throughout their height; the remainder was built in ordinary mortar; the lime is of admirable quality, moderately hydraulic, and has been exposed to very severe tests which it has stood satisfactorily. It was found by careful measurements that the total leakage into the enclosure after the latter was pumped dry was about half a cubic foot per second, of which quite half and probably more was through and under the shutters of the right byewash. The leakage between the front and rear walls and the rock is confined to a short length in each wall, and no difficulty is anticipated in stopping it completely when the enclosure is again cleared out."

METHOD OF PASSING RIVER DURING CONSTRUCTION OF PERIYAR DAM



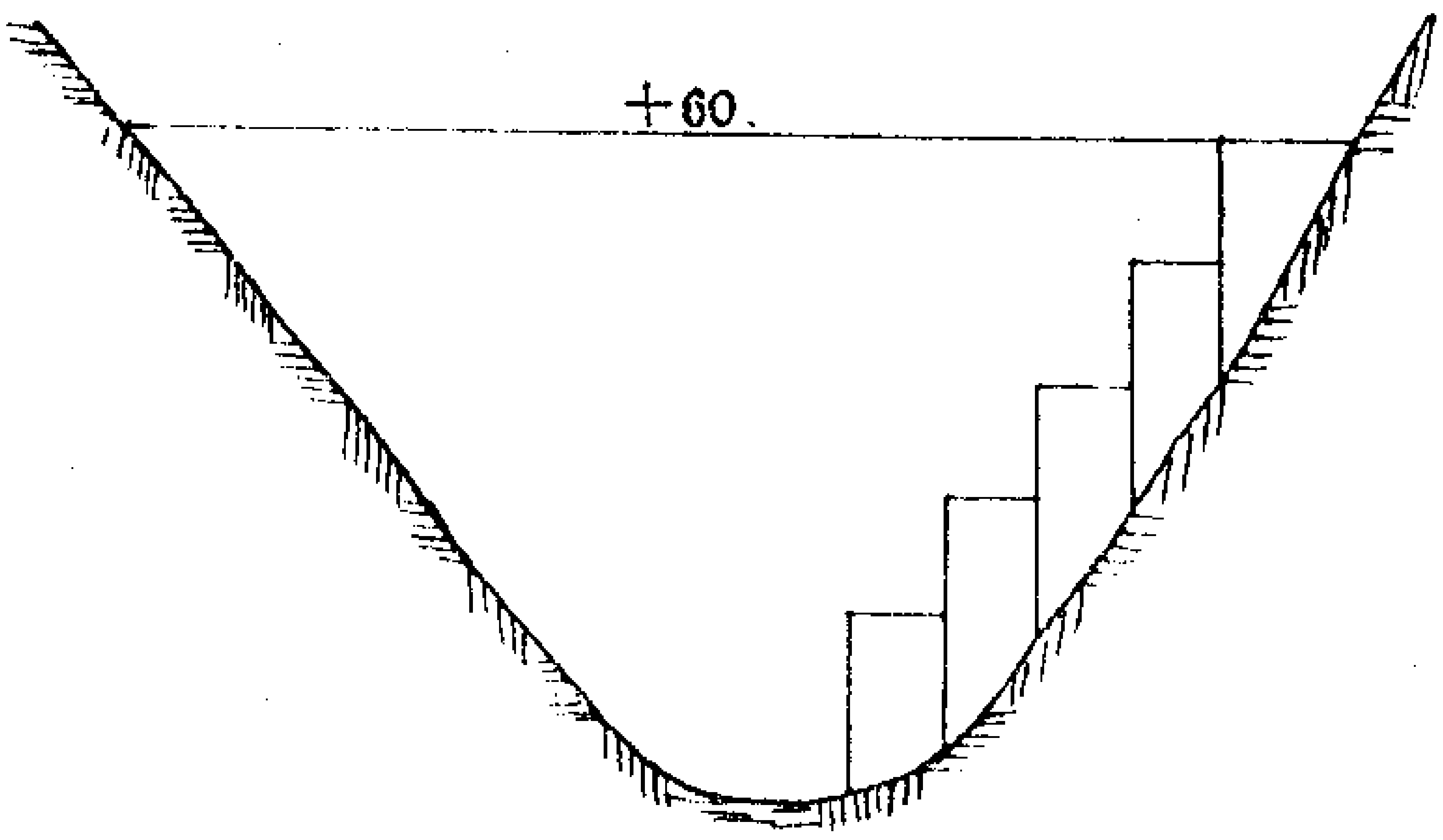
Reg: No. 4685
Copies. 410

Photo-Print, Survey Office, Madras.
1898

The operations above described from the beginning of December to the middle of April were described by the Chief Engineer, Colonel Pennycuick, in his report to Government, as the most anxious, difficult and exhausting of any that had come within his experience, and the staff received the thanks of Government for their services on this occasion.

Work was re-commenced at the end of June 1890, and as for some years the principal difficulty encountered was the control of the river during construction, it is necessary before proceeding further to touch on this subject. The method adopted for disposing of the normal discharge was in principle briefly as follows. All the water was turned round the right flank. Taking the foundation enclosure as a start the river was already raised and diverted, running through vents between piers built in the dry. Similar piers AA were built in the front line of the dam further to the right leaving vents with floors at a higher level, and these piers were connected with the line of the rear face of the dam by another line of piers BB with groves into which planks could be inserted. The height of these piers BB was so calculated that when the original byewash was closed and the river was turned through the vents AA the ordinary discharge of the river and small freshes should not top the piers BB. When the foundation enclosure reached a level equal to the piers BB the front wall of the dam was raised somewhat higher. The original byewash was then closed, the water rose and the river began to run to the right of the piers BB. The space between BB and the foundation enclosure was then rapidly brought up to the level of the work already built and was then included and the whole went on together. New piers CC and DD were then built in the dry, and as soon as the body of the dam reached a sufficient height the process was repeated, the river raised and diverted, and a fresh portion included. In this manner the dam was built up to the level of + 60.

This method had disadvantages. If the discharge of the river exceeded about 2,000 cubic feet a second the portion last included was at once flooded; and if the discharge exceeded what could thus be carried off (which it constantly did) the front wall of the dam was topped and the whole work submerged till the fresh subsided. There was thus a danger of damage to new work, and during the early days (when the lake formed above the dam was small and of little absorbing capacity) a considerable source of delay. This was, however, only a comparative evil. An absolute and constant disadvantage was that it caused the dam to be built piecemeal, and resulted in a series of vertical joints. A longitudinal section would show thus—



More than this it necessitated a great portion of the work being built under a head of water behind a front wall which had to be kept considerably in advance of the rest of the work.

There were besides some constructive drawbacks. The piers in the front line of the dam were several times washed away and had to be built very strong indeed, thus taking up a good deal of the waterway, always small on account of the steepness of the side of the hill. The transverse piers were also constantly washed away and the difficulty of replacing them in swift running water was beyond description. A continuous wall could not be substituted, or there would have been no bond between the body of the work and the portions successively included; nor could these piers be made very large, or the bond would have been insufficient unless wide intervals were left, and this again was impracticable, because of the impossibility of handling large shutters under the conditions that prevailed. Moreover when the earth was cleared from the side of the hill the rock exposed was not on a uniform slope but lay mostly in alternate dips and scarps, so that the space available for each fresh diversion channel was very unequal, and to ensure a reasonable discharging capacity the piers had sometimes to be brought very high. Finally, nearly all the materials, which were on the right bank, had to be carried across the river to the work. The bridges had to be changed each time the river was diverted and were constantly damaged by floods.

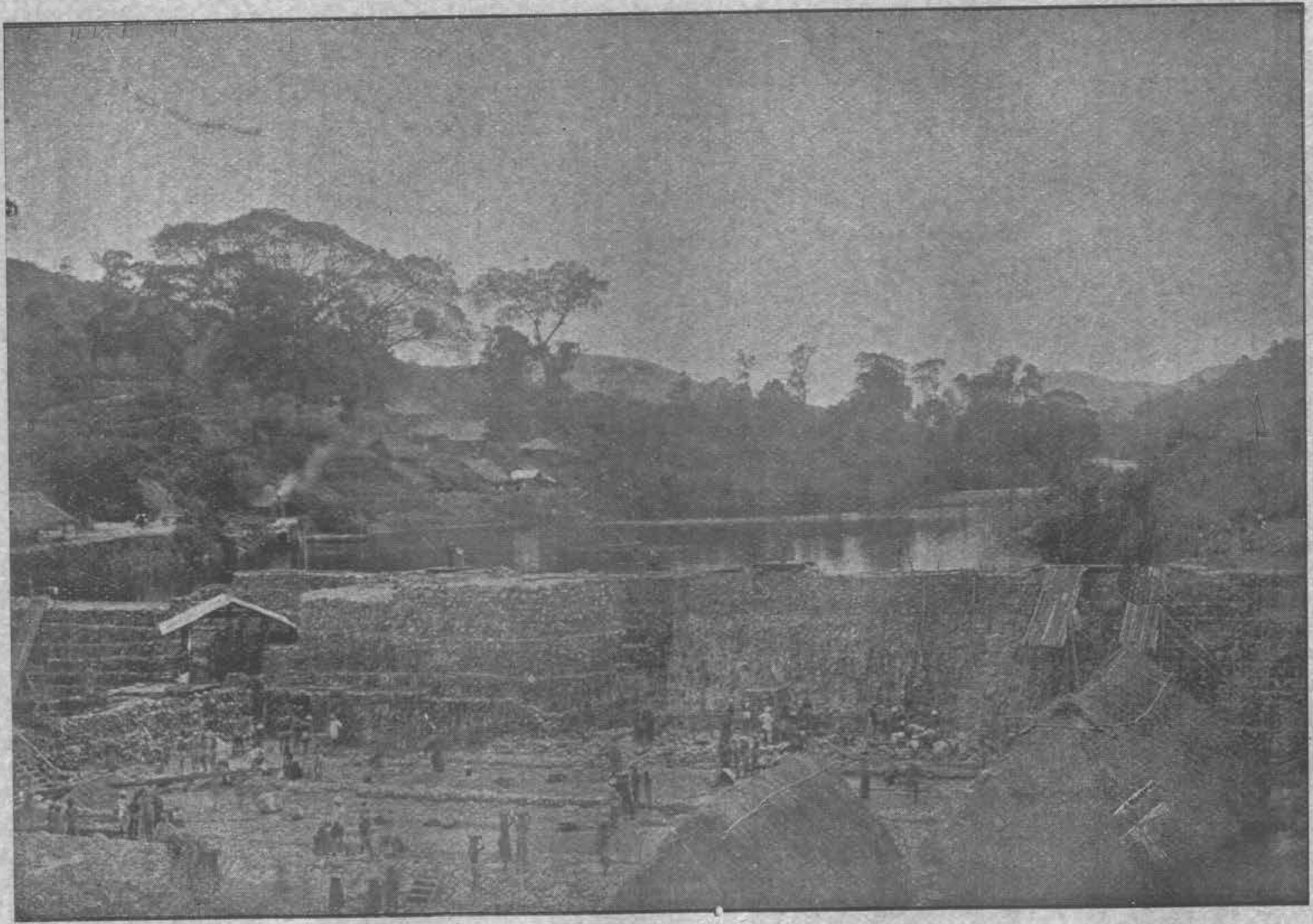


Photo-Block.

Survey of India Offices, Calcutta, 1899.

THE DAM DURING CONSTRUCTION.

It will be of interest to notice briefly the other methods proposed for dealing with the water during construction. The question, generally important in all large dams, was here accentuated by the torrential nature of the river, the volume of water it carried during a great part of the year, and the frequency of strong freshes from local thunder storms even in the dry months. There was no experience as a guide, since no dam has ever hitherto been built across a river so large as the Periyár and combining so many refractory characteristics. The south-west monsoon commencing here at the end of May continues with more or less force but without complete intermission till October, when it is replaced by the north-east monsoon, and rain continues to fall till the latter half of November. There is sometimes a partial break in August, but the weather is then always uncertain and the drainage from previous rain prevents the river from running low. From the rainfall register it may be seen that the number of rainless days between June 1st and November 15th was on the average but 34 for the years 1888 to 1895 inclusive. During this period the discharge seldom fell below 1,000 cubic feet a second. From the middle of November till the middle of May the weather is usually fine and dry but in these hills thunder storms are of frequent occurrence and a month seldom goes by without one, resulting in a fresh of greater or less violence. The highest recorded fresh reached the figure of no less than 120,000 cubic feet a second, while freshes of 10,000 to 20,000 cubic feet a second are not infrequent; and the rocky bottom of the river, its steep fall and confined bed cause great turbulence and a high velocity, a large flood running at the rate of 10 feet to 15 feet a second and bringing down with it big trees as well as a great quantity of other floating and rolling débris, which was a constant danger and trouble. It was almost impossible, at any rate generally impracticable, to build piers in the course of the river strong enough to permanently resist the impact of these floating battering-rams and nothing but a heavy continuous wall with a rock abutment successfully encountered them for any length of time, and then not without showing severe signs of the fray.

In the proposals submitted by Colonel (then Major) Pennycuick it was intended to drive two tunnels at a low level through the flanks of the dam, as described in Chapter I. The then Inspector-General of Irrigation took great exception to this proposal, criticising it in a note of which the following is an excerpt:—

"When in Madras the proposed arrangements were explained to me, and I then stated that I would never agree to so dangerous an arrangement, and suggested that if no other means could be contrived the water might be passed over the dam by means of large syphon tubes. Major Pennycuick stoutly maintains that his plan is the best of all possible alternatives, that no risk is ever to be apprehended from its adoption, and that it combines in the highest degree the elements of security, efficiency and economy. Having most carefully considered all Major Pennycuick's proposals and arguments, my objections to the culverts remain absolutely insuperable. I cannot conceive how an Engineer of his intelligence could have brought himself to devise such a method of disposing of the escape water. A glance will show how soon floating brushwood and grass would clog and jam the self-acting sluice. The "draw" into the tunnel would of course be very great, and unless the floods in the Periyár run quite clean and free of floating rubbish I don't believe the sluice would remain in working order one hour after a flood began to come down. Again, supposing it to remain in perfect order, it is quite plain that the powerful eddy generated by the cross currents at the entrance of the tunnel, would block the mouth so as to reduce the discharge immensely. This would necessitate a larger section against the adoption of which Major Pennycuick himself protests. But again, supposing the tunnels to have answered all expectations during construction, I cannot well imagine a more fatal source of danger to a lofty dam than two culverts passing underneath its flanks, closed by shutters exposed to the enormous pressure due to an average head of at least 135 feet of water!!"

The Inspector-General then went on to state briefly his belief that the water could easily be passed by leaving 200 feet on either flank alternately 2 feet and 4 feet below the rest of the work.

The objections, it will be seen, were directed against the following points: (1) against the gear by which the sluices were to be actuated, (2) against the adoption of either a greater section or a greater velocity in the culverts, (3) against the existence of a culvert of any kind through the dam when completed.

There can be no possible doubt that, speaking generally, in a case of this kind culverts are by far the best plan of disposing of the water from the point of view of convenience and construction. Nearly every large dam is built so, unless there are very special reasons favouring another method. It has the immense advantage of keeping the water low throughout the progress of the work, which is, therefore, built without joints and without a head of water outside it, and is allowed any time that may be wished to set before resisting horizontal pressure. Both syphons and flank depressions entail raising the water as the work advances and keeping the two at nearly the same level. The cohesive material in the present case being a good but not extraordinary and only moderately hydraulic lime, more objectionable conditions can hardly be imagined. Both these methods too bristled with constructive difficulties which, had the Periyár been an insignificant stream, could have been surmounted, but in such a river were insuperable. When it came to the point the syphons were speedily dismissed as impracticable, and the water was actually passed not over but round the flanks in the manner previously described, thus avoiding at any rate horizontal joints. But the cost, the damage, the innumerable inconveniences may be said to have delayed the completion of the work a full year and added to the expense a sum variously estimated at from 1 to 4 lakhs of rupees. The drawbacks were indeed so intolerable that when the dam reached the level of + 60 this method was finally abandoned and the water was passed by a tunnel or culvert through the dam. It gave no trouble, it was easily controlled, and eventually closed and plugged without the slightest difficulty.

The Inspector-General's first objection was to the sluice arrangements, which could however have been designed differently. Most of the floating débris could have been arrested by a boom across the river, as was actually done at one stage of the work, and another type of sluice with suitable gratings need have caused no anxiety. The principle laid down was that 20 feet per second should be the limiting velocity through the culverts, and gearing could easily have been devised which would work satisfactorily under a head of 30 or 40 feet, that is to say until the dam reached a level of about + 50. At this level similar culverts might have been made and the original culverts closed. These could control the river until the dam rose to + 100, when the depression on the left flank was available as an escape. In several large dams culverts have been left which work easily under a head as great as this, and at Bhátgarh such culverts after being used to scour out silt are closed and remain closed under a much greater head. On the whole, therefore, it seems insufficient to have rejected for this reason what was obviously the best plan on other grounds.

There is apparently a misunderstanding underlying the Inspector-General's second objection, viz.: that the area of the culverts must be increased in order to obtain the required discharge or else a greater velocity must be expected. The approaches to the culverts as proposed, were to be tunnelled out of the solid rock and in these the section might have been enlarged or the velocity increased without serious objection. The covered cutting was quite straight and had a clear outfall, and the discharge and the velocity must have been very nearly according to calculation. In any case the floor was purposely intended to be benched out of the solid rock and a slightly increased velocity was of slight importance.

The third objection referred not so much to the culverts themselves during construction as after the completion of the dam. There was no crying necessity for the culverts to remain, since the Periyár is not a silt-bearing river, and as the lake could not silt up in any measurable length of time no scour was needed. By choosing a favourable moment when the river was at its lowest there would have been no trouble in eventually plugging them, and very simple means would have sufficed to make such plugging sound from a constructive standpoint, that is to make a good and firm junction, well bonded in and practicably free from leakage. The culvert afterwards used at + 60 was plugged in such a manner as to be free from leakage and indistinguishable from the rest of the dam in appearance. The culvert used during the construction of the Vyrnwy Dam was plugged with but 15 feet of brickwork and is perfectly tight, and the addition of an asphalte expansion joint removes the matter from the possibility of doubt. It may, on the whole, be laid down as an axiom that almost no obstacles should prevent the adoption of low level escape culverts in a large dam. Difficulties with the sluices or delay in the first installation will be many times repaid in subsequent speed, cheapness, and convenience of construction, and in the quality of the work turned out.

The narrative may now be resumed. On the recommencement of the work in June 1890 the foundation enclosure was pumped out and cleared of about 80,000 cubic feet of slush and decayed rock, and the solid rock laid bare. The surface was found to be exceedingly irregular and rough, and no benching was required, the more so as the bed sloped the reverse way to the fall of the river and sliding was impossible. The leakage through the front and rear walls had then to be suppressed, for which purpose walls of rubble masonry were built 3 feet behind each and pulsometers placed between to keep down the water. As soon as these walls were completed the water was allowed to rise and a 6-feet seal of cement concrete was formed either by depositing from skips or by forcing grout into broken stone previously laid. After the concrete was set the water was pumped out and the space was entirely filled with concrete of surki mortar. This made the front and rear perfectly

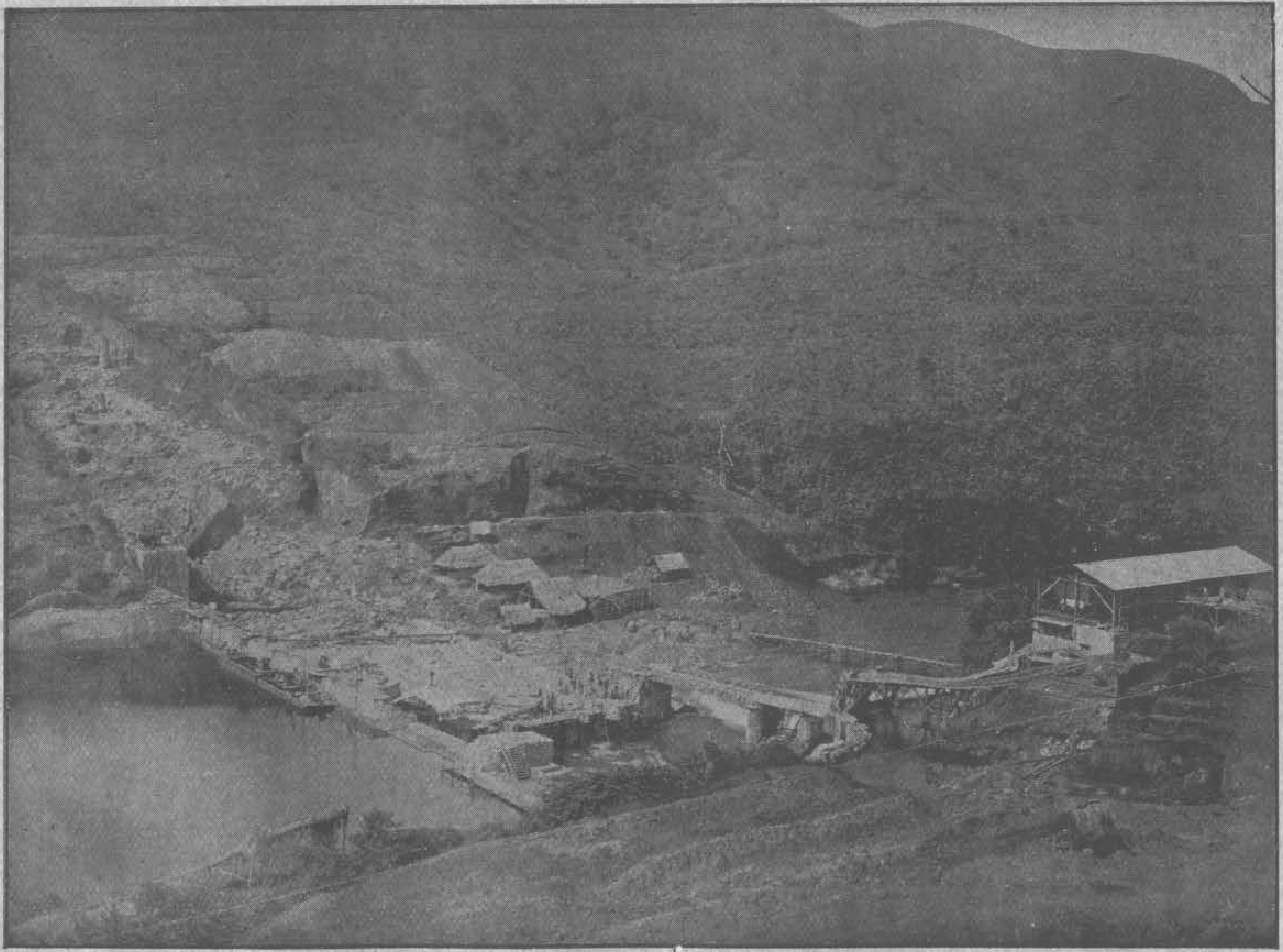


Photo-Block. Survey of India Offices, Calcutta, 1899.

THE DAM DURING CONSTRUCTION.

watertight, and the only other leakage was through the shutters on the right, to stop which the spaces between the piers were closed with rubble masonry, thus forming an irregular continuous wall. The foundations were thus perfectly enclosed and work inside could proceed uninterruptedly except when a flood in the river overflowed everything.

The deep bed of the river, though of undoubtedly solid rock, contained a number of small springs, each of which was confined in a well of cut stone in cement 6 inches in diameter, which was brought up with the rest of the work. It was found that these springs ceased to rise after a depth of 6 or 8 feet had been reached, and they were then all sealed with cement grout. The river bed was meanwhile divided into partitions by 2-feet walls of rubble masonry and the partitions were filled with concrete. By the end of the season (April 1891) the concrete was raised to an average level of + 0, or a depth of 15 to 18 feet in the deepest place.

On the right of the front wall and in a line with it four new piers were built leaving four vents with sill level at + 10. The piers built the previous year in immediate extension of the front wall at the right, through which the river had hitherto been running, were washed away, so the river was diverted by a bank of sand bags and a solid wall built in extension of the front wall left at + 16 to serve as a weir. The normal discharge then flowed through the vents at + 10. The original front wall was then raised to + 30 and thickened, and the extension to + 20, and more piers were built in continuation on the right, leaving vents at + 17, + 20, and others higher. From the vent at + 17 piers running across the dam were built and continued to the workshed, and the river being then again diverted and raised to these vents the water was available for the turbine.

A great deal of earth and boulders was also excavated from the site of the dam on both flanks. The trial pits dug for the purposes of the estimate were thought to disclose solid rock at from 10 to 35 feet below the ground. In some instances rock had unmistakably been exposed, in all the trial pit was always continued through several feet of water and the bottom carefully sounded with steel jumpers before it was concluded that solid rock had been reached. There were thus good grounds for the belief, but it did not by any means prove always correct. The regular sequence was dark vegetable mould, red clay hard when dry but slushy when exposed to water, then small boulders, then larger (sometimes enormous) boulders; and it was these that the trial pits had occasionally stopped on. In the excavation for the dam it was often 50 or 60 feet from the top before real rock was reached, and the surface needed a good deal of blasting and scaling with pick and chisel before being fit to build upon. The danger of a sloping bed, however, seldom occurred, since the lie of the rock was not uniform up the side of the valley but in alternate flats and scarps. No precautions were, therefore, taken against the sliding stress down hill.

These operations closed the working season 1890-91. The total quantity put into the dam was not great, but every operation was one of difficulty, and the whole work was so near the normal level of the river that it was constantly submerged and interrupted by floods.

Work was recommenced at the end of June 1891. From this point things became comparatively easier and more regular, but interruption and damage by floods were not infrequent. The south-west monsoon was fairly benevolent, but in October the work was entirely submerged on five separate occasions and 7,000 cubic feet of rubble masonry and 20,000 cubic feet of concrete were washed out; and in November it was submerged four times. These floods, though they did not damage appreciably the main dam itself, often washed away piers or other isolated structures, which had to be replaced with infinite trouble in the full force of the stream. There were very many such incidents of which no detailed record has been kept. It was so impossible to procure articles specially fitted for the service under ever-varying conditions, that anything which happened to be on the spot was impressed into use. For instance the current was stopped on one occasion by a large bamboo raft loaded with sand bags till it sank, on another by an abattis of trunks of trees and thick steel jumpers, in fact anything that would so far break the current as to allow a bank to be raised of sand bags or heavy stones. The current was often so strong that stones of 8 or 10 cubic feet, in weight, perhaps, $\frac{3}{4}$ of a ton, were rolled easily along the bed. This kind of work was interesting, but made great calls upon the resource and energy of the staff, and the delays and interruptions were harassing in the extreme. Nevertheless the average monthly progress gradually increased as was to be expected with improved organization and experience. By the end of March 1892 the front wall was raised to + 37 and the cross wall bounding the diversion to + 33, the rear wall to + 23, and the concrete in the enclosure to an average of + 13. Three new piers making vents at + 30 were also built in continuation of the front wall on the right. The total quantity put into the dam during this season (1891–92) was—

	CUBIC FEET.
Concrete	544,750
Rubble masonry	274,003
Total ..	818,753

the highest combined outturn in any month being 148,097 cubic feet in February 1892.

The work was submerged in April by a flood which rose 20 feet in twelve hours and carried away two piers of the turbine weir, and again in July when the rest of the weir was carried away and the bridge across it overturned. The weir was re-built solid instead of with piers, but meanwhile the turbine was idle and work greatly delayed and no real progress was made on the main dam till the middle of August. From this time it was rapid and uniform. In January 1893 the dam had advanced so far that it became necessary to include the channel through which the river had been running for the last two seasons, and to make a new byewash on a higher level. Two of the vents were closed without difficulty, the third being postponed till March and necessitating a lift of 20 feet to the river. This, one of the many arduous incidents that were an every-day occurrence, is described in an extract from the Progress Report for March 1893.

"On the 5th evening under a blue sky with light passing clouds and with a high barometer, the wrought-iron semi-cylindrical shutter was lifted by a gantry and moved laterally into position in front of the vent to be closed. The sill level of the vent was + 21, but in order to give access to a new sand bed 5 miles above the dam, plank shutters had been dropped into the vent in January up to a level of + 29, over which 2·20 feet of water was passing on the fifth. The river level was, therefore, + 31·20 at the time of shifting the W. I. shutter, and judging from the fact that at the closing of the adjoining vent the river had occupied nearly 13½ days to rise from + 20·50 to + 31, it was to be inferred from the known contours and capacities of the lake at successive levels that it would occupy nearly five weeks in rising from + 31 to its new minimum level of + 43, at which it would be passing through the new vents having their sills at + 41. This would have given ample time to build up the vent behind the W.I. shutter and to build a coffer dam wall along the rear toe of the dam across the old turbine channel to prevent the water passing through the new vents (when it should reach them) from backing into the site of the dam immediately behind the W.I. shutter. At 3–30 P.M. on the 5th the shutter was in position fairly watertight, with a little caulking only to be done and with a pulsometer in position in the sump behind it to pump out any small unavoidable leakage. Heavy rain must, however, have fallen at the source of the river during the day and for many days following, for though the barometer and the aspects of the weather at Periyár continued very favourable, the river began to rise in the afternoon at a much greater pace than was anticipated and before the caulking could be finished or the masonry fairly begun it had reached the level of the new vents by midnight on the 6th. The shutter was artificially increased 4 feet by the addition of a plank ring, and the shutter itself radially strutted to resist the increased pressure thereby engendered, but the river continued to rise notwithstanding that the weather continued fine, and by the 9th evening the water was flush with the top of the plank ring. During the 9th night the river rose very quickly, reading 45·10 at 7 P.M., 49·50 at 3 A.M. (10th March) and 50·15 at 8 A.M. It fell again to 47 by the 11th morning, when it was found that the plank ring had gone, the iron shutter itself remaining uninjured. By the 13th morning it had fallen to 43, but during the flood so large a quantity of débris had come down the river, passing under the boat house boom, and over the shutter, that the top ring was battered in, and losing in consequence its virtue as an arch was torn away from the second ring and was subsequently found in fragments below. The position of affairs at this point was, therefore, that about 6 feet of water was passing over the top of the iron shutter (now shortened by 4 feet by the loss of the top ring) and 2 feet of water through the vents, and the problem of stopping the water passing over the iron shutter remained. The river fell slowly till it reached 41·60 and remained stationary. A wooden barge was at 10 A.M. on the 20th floated over the shutter and loaded with earth till it rested lightly on the second (now the top) ring, the top edge of which fortunately remained intact and perfectly horizontal, making a fairly good joint with the bottom of the boat. The middle of the boat being over the air space enclosed by the shutter and consequently unsupported except by the buoyancy of the remainder of the boat, care was taken to load only the floating portion of the boat, so as to strain it as little as possible. A number of gunny bags were next stitched end to end and twisted into a rope, which was lowered round the outer side of the boat and pulled tight along the joint between the shutter and the boat bottom. The boat being then slightly lightened till the draught of water between the boat and shutter drew the rope well into the joint, the boat was again loaded and an almost perfectly tight joint achieved. A single pulsometer would, at this point, have been sufficient to deal with the leakage, but misfortune was not to end here, and the next event was that a fragment, fortunately small, of the masonry ring on which the shutter rested blew in, admitting under the head of 20 feet a flow far beyond the capacity of the pulsometer. Sand bags were thrown in front of this new leak which reduced its discharge to about 2 cubic feet a second, and an 8-inch centrifugal pump with the pulsometer would now have sufficed to keep down all the leakage. But the difficulty of getting an engine on to the front wall and of fitting up a centrifugal pump would have been such that it was decided in preference to try syphons: 3-inch plank shutters were therefore put in to a height of 12 feet across the face of the vent behind the iron shutter and carefully caulked, so that the water between them and the iron shutter should form a tank 12 feet deep, and with the head thus obtained two syphons of 4-inch piping were found sufficient to dispose of all the leakage, except a very trifling amount through the plank shutters between which and the face line of the dam there was just room to insert a pulsometer. Masonry in portland cement was begun on the 23rd afternoon and it was thought best to work only by day, as it has been repeatedly found that progress is incomparably better in quality and inappreciably slower with day work only. It was moreover of the greatest importance that the masonry should be absolutely watertight, as it will, during part of next season, have a head of more than 20 feet against it with concrete in progress behind it. The time of filling in the vent was one of the greatest anxiety, for though the normal discharge of the river in March should have been easily passed by the new vents without topping the boat as it rested on the iron shutter, the river continued to rise steadily from the moment the boat got into position till a depth of 4½ feet was running through the vents indicating a discharge of about 550 cubic feet a second, or about seven times as great as the discharge all through December, January and February. The boat during this period was kept from being topped by raising the three outer sides with planking, caulked and strutted, and as its buoyancy was thus greatly increased, causing it to lift off the shutter, the greatest care had to be exercised in loading it—as the river rose—so as to keep the joint tight, and in lightening it as the river fell to prevent all chance of the shutter buckling under its weight. The river did not rise beyond 45·50 however and the masonry was completed without accident by 4th April. After keeping the syphons and pulsometer at work for another week the water was allowed to rise against the new work and the sweating through it is all but imperceptible. The operation of closing this vent extending over 30 days was one of great labour and anxiety, and the whole available staff of officers and upper subordinates were engaged in it by night or by day."

The condition of the dam in April 1893 was then as follows :—

The front wall + 60 throughout except 152 feet at the left flank kept back at + 50 to serve as a weir. The concrete at an average level of + 38, with the rear wall of such height above the concrete as to ensure a sufficient water-cushion in case of the front wall being topped. The total quantities put in during the year were—

	CUBIC FEET.
Concrete	432,622
Rubble masonry	513,385
Total ..	946,007

the greatest aggregate in any one month being 158,935 cubic feet in December.

His Excellency the Governor of Madras visited the works in October 1892.

During the next season (1893–94) the absorbing capacity of the lake grew so much that the work was never entirely submerged, though water sometimes passed over that portion on the left flank which had been left low as a weir. Even this short experience proved conclusively what the effect would have been had this method of disposing of the river been adopted *en bloc.* As soon as the brunt of the south-west monsoon was over, this low portion was brought up to the level of the rest and the river was then raised from vents at + 41 to vents at + 48, an operation which gave little difficulty except that the vents to be closed were arched over and trouble was experienced in making a watertight joint with the crown of the arch. This was done by leaving a ring in the filling and in the soffit and grouting with cement under pressure. It was found that the concrete flooring extending over the whole width of the dam behind these vents and over which the discharge had been passing for nine months with a velocity of occasionally not less than 20 feet a second and seldom less than 10 feet a second was almost absolutely uninjured. This concrete had not even been plastered— a fact which speaks volumes for the quality of the mortar; but there had grown on the surface a thin slime of a nature which was not investigated, but which seemed to afford a complete protection on a smooth surface. The method which had been found by constant trial and error to be the handiest for closing these vents and raising the river in short lifts was briefly as follows :—

METHOD OF CLOSING VENTS FOR A SHORT LIFT

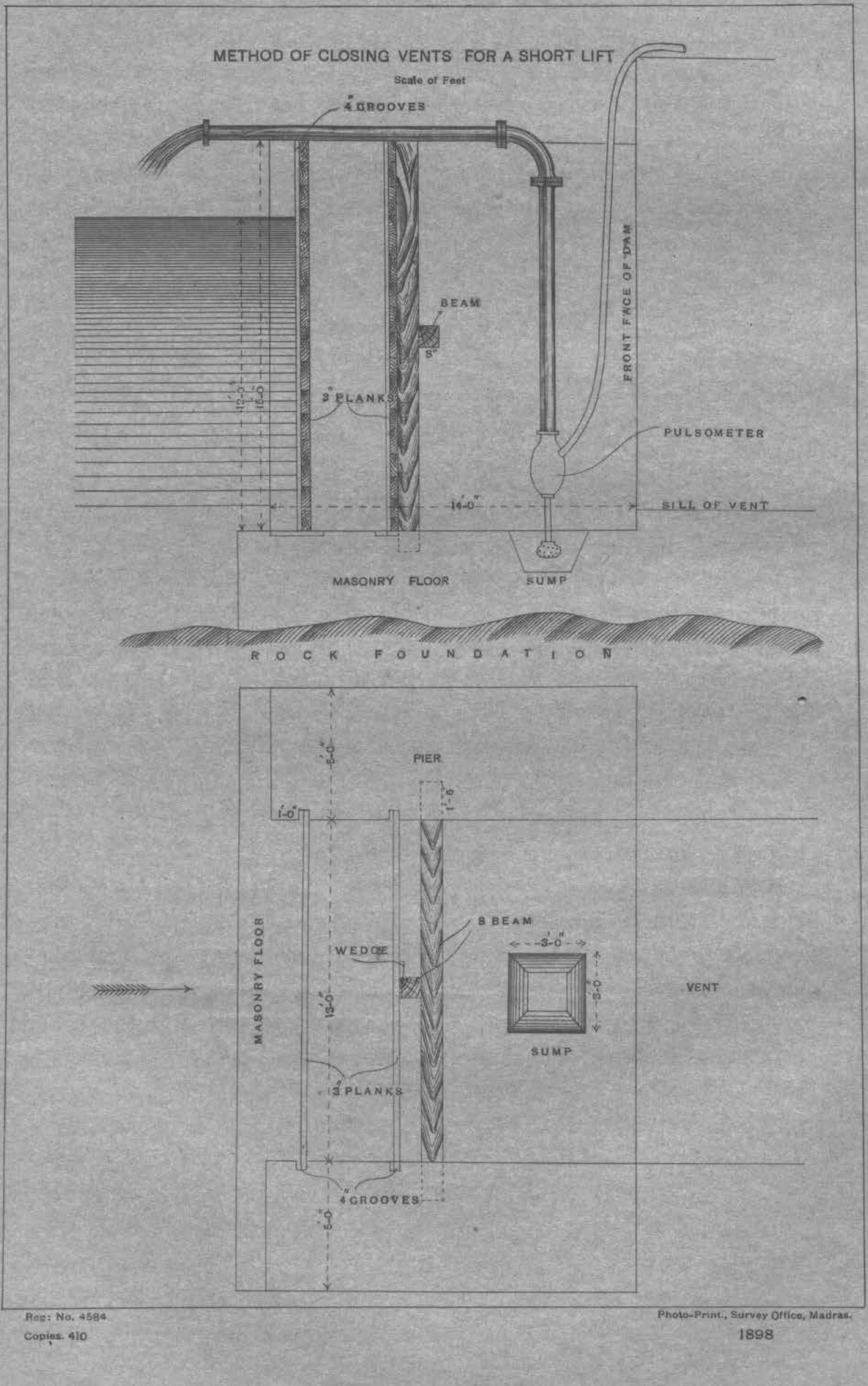


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Photo-Print., Survey Office, Madras.
1898

In front of the upstream face was built a flooring of masonry to 1 foot below the sill of the vent, and on this flooring two strong piers each with two grooves, a stout wooden beam being built into the piers immediately behind the second pair of grooves. Between the sill and the second groove a small sump was left. The grooves were rendered smooth with cement, and also a length of the floor 1 foot wide in line with each pair of grooves. All this was done in the dry before the vent was brought into use, and the river was then turned through the vent. As soon as it became necessary to close the vent and raise the river to a higher level, an opportunity was selected when the river was low and the stream in the vent not more than 4 or 5 feet deep if possible, the velocity being about 10 feet per second. Three-inch planks a foot wide were then dropped into the front grooves and hammered down with heavy wooden rammers till they nearly reached the bottom. This broke the force of the stream, but no attempt was made to make these planks watertight. Similar planks were hammered down much more carefully in the second pair of grooves, and heavy vertical timbers resting against the horizontal wooden beam were at the same time inserted in holes left in the floor, against which the planks were straightened by wedges. Otherwise they gave considerably. The planks were then caulked. The lowering of the planks was effected by ropes passing through holes in them, afterwards stopped with wooden taper plugs. This enabled most of the planks to be withdrawn and used again. The leakage through the second row of planks was generally small enough to be disposed of by a bucket or a small pulsometer, but in the rare cases when it was more the space between the two rows of planks was filled with sand bags and earth. This, however, entailed extra strutting. The arrangement always proved satisfactory, the only troublesome part being hammering down the bottom shutters. Behind the screen thus formed the masons were able to build up the vent perfectly dry and the whole operation seldom exceeded three or four days.

The progress on the main dam was steady and uneventful, and by the end of February the following total quantities had been put in:—

	CUBIC FEET.
Concrete	752,935
Rubble masonry	215,323
Total ..	968,258

the greatest aggregate in any one month being 172,350 cubic feet in January 1894. The front wall was at + 80 and the concrete at + 68, a culvert with floor at + 60 having been begun. This was arched over during the recess.

The works were closed for the season early in March on account of an epidemic of cholera which commenced in the middle of February and which no exertions could arrest. The coolies speedily dispersed to their homes and by the first week in March had dwindled to a few hundreds, the camp was burnt, and preparations made to transfer it to the other side of the river.

The tunnel or culvert through the dam must be the cause of a slight deviation from the continuous narrative, since it is not only of professional interest but was the subject of some correspondence. When the Government of India heard of its construction a despatch was addressed to the Madras Government calling attention to the very strong objections to a tunnel raised by the Inspector-General of Irrigation before the estimates were sanctioned, and inquiring why syphons, as then proposed, were not employed; and adding that they were unable, from the information received, to follow the proposals of the Madras Government or to comprehend how the lake was to be regulated and floods disposed of. In reply the Madras Government forwarded a copy of the specification and a note by Colonel Pennycuick, Chief Engineer, of which the following are extracts:—

"A tunnel to be left in the body of the main dam 10 feet wide by 8½ feet high to springing of arch, which is to have a radius of 6¼ feet and rise of 2½ feet.

"The centre of the tunnel to be where the level of the rock at the front face is 60·00 above datum, and the heights to be measured at the centre. They will be a little more or less at the sides according to the lateral slope of the rock. If the rock falls from front to rear the crown of the tunnel to be kept level. If it rises the crown to be raised to correspond in steps of 10 feet width with a minimum height of 11 feet between floor and crown, the rock always forming the floor.

"The sides and soffit to be plastered with good surki mortar.

"In front a masonry chamber to be constructed 10 feet wide (in the direction of the length of the dam) and 12¼ feet long, to be surrounded by a wall 10 feet thick on three sides, the fourth side being the dam itself. The wall to have its crest at + 74·00, except for a space of 14½ feet square,

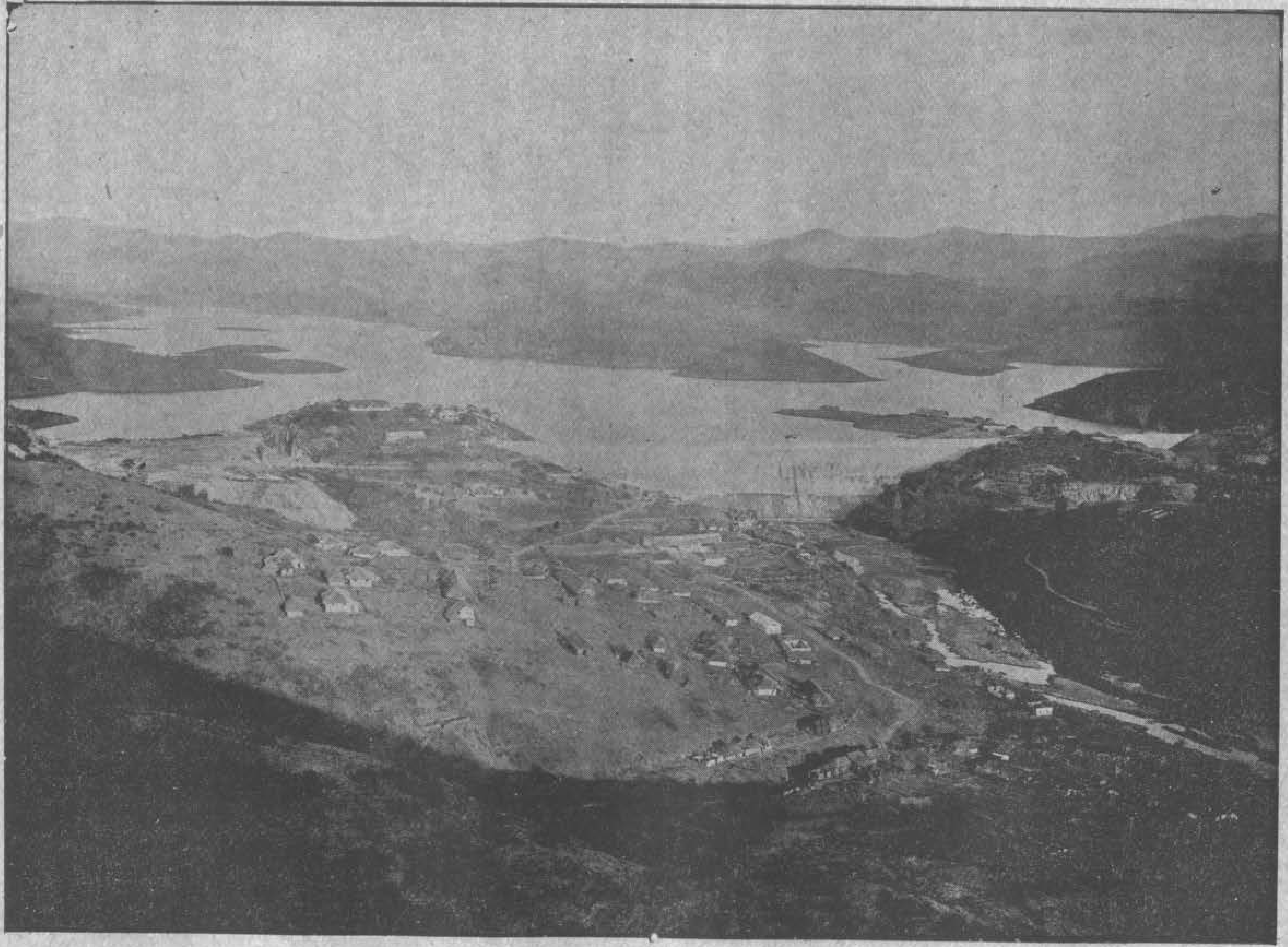


Photo.-Block. Survey of India Offices, Calcutta, 1899.

THE LAKE FROM BELOW THE DAM.

as shown in the drawings, which is to be at + 73·50. This space to be surrounded on three sides by cutstone 2 feet wide and 1 foot deep set in portland cement.

"Two and a quarter feet in length of the chamber being the portion nearest the dam to be arched over with an arch similar to that of the tunnel. The remainder of the chamber to be open at top.

"In the lower side wall of the chamber, the side nearest the river bed, an arched vent to be left, 10 feet wide for the outer half of the wall and 9 feet for the inner half with sill at + 60·00 and crown at + 67·00, the rise being 1½ feet.

"Two lengths of 40 lb. rails to be built into the masonry across each corner of the chamber at top, one to rest at 2½ feet from the corner, the other at 1¾ feet, the upper surface of rails to be at + 73·50.

"A seating for a semi-circular iron shutter to be built in front of the vent in the side wall up to + 60·00."

"The regulation of the discharge through the tunnel is effected as follows (see Plate X).

"The top of the chamber at the mouth is closed by a plate of cast iron 14 feet square with an opening 10 feet in diameter. This plate fits into a recess in the top of the masonry 14½ feet square, so as to leave a space of 3 inches all round between the side of the recess and the side flanges of the plate, to be packed in with neat cement. When the vent in the side wall of the chamber is closed the only route by which the water of the lake can find access to the tunnel will be through the circular opening in the covering plate.

"At a distance of 4½ feet above the covering plate is fixed a horizontal circular plate. This plate whose outside diameter is the same as that of the opening of the lower plate is supported by 24 uprights of 40 lb. rails imbedded in the floor of the chamber with sockets at top and bottom, and bed plates under the bottom sockets.

"The circumferential space between the top and bottom plates is closed by a W.I. cylinder of sufficient size to move easily over the outer flange of the top plate, to be lifted by a winch on a floating platform and kept in position horizontally by guides.

"It is evident that as the water has free access all round this cylinder it will be in complete equilibrium and its own weight will be the only resistance to be overcome in lifting it. The admission of water to the tunnel can thus be properly regulated. The discharge through the tunnel is to be limited to 12,000 cubic feet per second, and so long as the discharge of the river does not exceed this amount the surface of the lake can be maintained constantly at any level that may be desired. When this discharge is exceeded the water level must rise until it reaches the vents in the Left Bank Extension.

"The vent in the left face of the chamber wall is to serve for the passage of water while the lake is rising to the level at which it can discharge freely through the tunnel (about + 77 or + 78); and at the end of the season it will be permanently built up from behind an iron semi-circular shutter.

"Until the dam is completed the water of the lake should not be allowed to rise above + 120, to which level it can easily be kept by the combined available methods of discharge. When the dam is completed the water will be run down to the sluice, which will be closed and caulked with lead."

Then follow some directions as to closing the tunnel, which need not be set down, as a different method (described on page 87) was afterwards preferred. Colonel Pennycuick then continues:—

"I have kept silence for upwards of ten years on the subject of the objections of the Inspector-General for Irrigation, and should prefer to keep silence for ten years longer. In the present connection it is sufficient to say that the decision of the Government of India to prohibit a low level tunnel, unfortunate though I consider it, has been accepted and loyally adhered to, but that I do not consider there is any analogy between such a tunnel and the one now under consideration which is half way up the dam, which has never to be worked under a head of more than 46 feet, and which is controlled by apparatus entirely free from the objections which might rightly or wrongly be urged against some of the details of the original designs.

"With regard to the proposal for disposing of the water by syphons, it was sketched out at a few minutes' notice at the urgent request of Colonel Hasted, who pressed me to design an alternative arrangement which would meet the objections. I never had very much faith in the plan and it is somewhat remarkable that this hasty and ill-considered scheme, which when carefully examined bristled with defects, was accepted without objection, while the immeasurably superior plan first proposed was peremptorily vetoed."

The floor of the tunnel or culvert, it may be added, was not rock but on account of structural drawbacks was built up level with ordinary concrete, which was also the material of the sides and arch. When the water was shut off, not a stone was displaced. To prevent sliding of the plugging and to give a better outfall, the culvert was given a curve in plan, and key-ways were left in the side walls, closed temporarily with stone laid in perished lime, and plastered. These were also undisturbed.

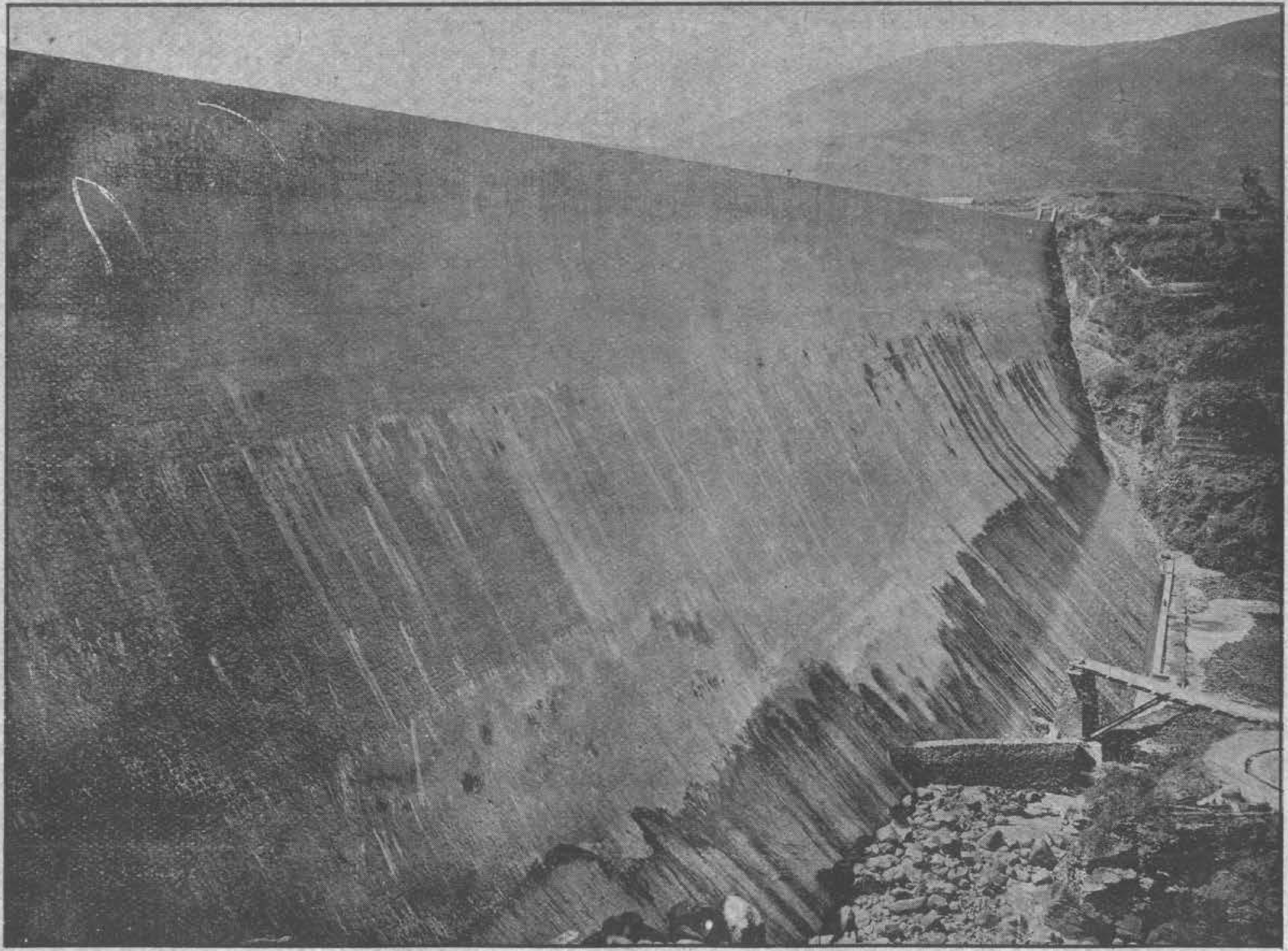


Photo.-Block. Survey of India Offices, Calcutta, 1899.

DOWN STREAM FACE OF DAM.

To return to the narrative, any doubts that existed as to the possible unpopularity of the works on account of the epidemic referred to on page 84 were at once set at rest during July by the influx of a larger amount of labour than usual, and work at once proceeded briskly. A new camp had already been built on the south side of the river and a foot bridge was in course of construction. In August the river was raised from the vents at + 48 to + 54, and an unsuccessful attempt made to raise it further to + 60, which was however satisfactorily accomplished in September. The water was then allowed to flow through the culvert just described and was controlled by the specially designed sluice of which a plan is given (see X), but the absorbing capacity of the lake had now become so large that there was seldom a formidable rise in the water level and the sluice was hardly required. The raising of the dam was continued over the culvert and the concrete throughout the whole length maintained at a uniform level thenceforward. With the employment of this culvert all anxieties on account of water ceased and the progress on the dam was rapid, uniform and uneventful. During the season (1894–95) the following quantities were put in :—

	CUBIC FEET.
Concrete	1,028,404
Rubble masonry	524,252
Total ..	1,552,656

the highest aggregate in one month being 198,681 cubic feet in November 1894. During the season the dam was raised 47 feet, viz., from + 68 to + 115. The bed of the cutting leading to the watershed tunnel being at + 115, and the front wall of the dam at + 118, it was now possible to turn water into the plains of Madura after closing the culvert at + 60 and allowing the lake to rise. At the end of March it therefore only remained to block the culvert, which during this month was left completely open so as to run the lake as low as possible. On the 2nd April morning, the gauge reading 63, the W.I. semi-circular shutter of 17 feet diameter, used on several similar occasions, was lowered by shear-legs on to a semi-circular masonry seating previously prepared in front of the vent. A pulsometer was then dropped into a sump in the masonry floor within the shutter, and with the help of a little caulking between the edges of the shutter and the sides of the vent the leakage was reduced in three hours to practically *nil.* The shutter being capable of being bolted up to 20 feet height at an hour's notice the culvert was now safe from inundation provided the pump did not break down or the lake rise more than 17 feet. As an additional precaution against these remote contingencies the vent was closed behind the iron shutter by 3-inch planks carefully caulked. At 11 A.M. the masons were set to work to build up the culvert with rubble in mortar, working day and night by electric light. In the following ten days the lake level had risen less than 1 foot; the blocking had been completed to a thickness of 25 feet, and though it was afterwards continued slowly the operation was to all intents and purposes complete, and the coping stone set to an unprecedently successful season's work. A good deal of interest at the end was lost owing to the abnormally small discharge of the river, due to the unexampled drought of the previous four months.

By July 1895 the water in the lake rose to + 110 and was passed for the time being through vents previously built across the depression on the left flank. During the remainder of the year the dam progressed rapidly towards completion and in October the works were formally opened by His Excellency Lord Wenlock, G.C.I.E., G.C.S.I., who laid a stone on the top of the dam in the presence of a distinguished assemblage to commemorate the occasion, the level being 129 feet higher than a similar stone laid by him at his last visit exactly three years before. Little then remained to do but the parapet walls, which were finished in December. A culvert had been left on the right flank at + 112, which was closed without difficulty in the following month, and the finishing touch was put by a pedestal at the north end, on the top of which are stones recording the names of the officers and upper subordinates who took part in the work. This closes the account of the construction of the Periyár Dam, a work unique in the history of engineering—built amidst unprecedented difficulties across a turbulent river, whose highest flood discharge exceeded that of the Thames at Windsor fifteen times and was equal to half the average flow of Niagara: impounding a lake covering more than 8,000 acres and with a maximum possible depth of 176 feet.

Large dams such as these are never, it may be said, free from leakage, and comparatively the Periyár Dam is remarkably watertight. A certain amount of sweating and a few actual leaks there are, but the exact amount of water that passes through them it has not yet been possible

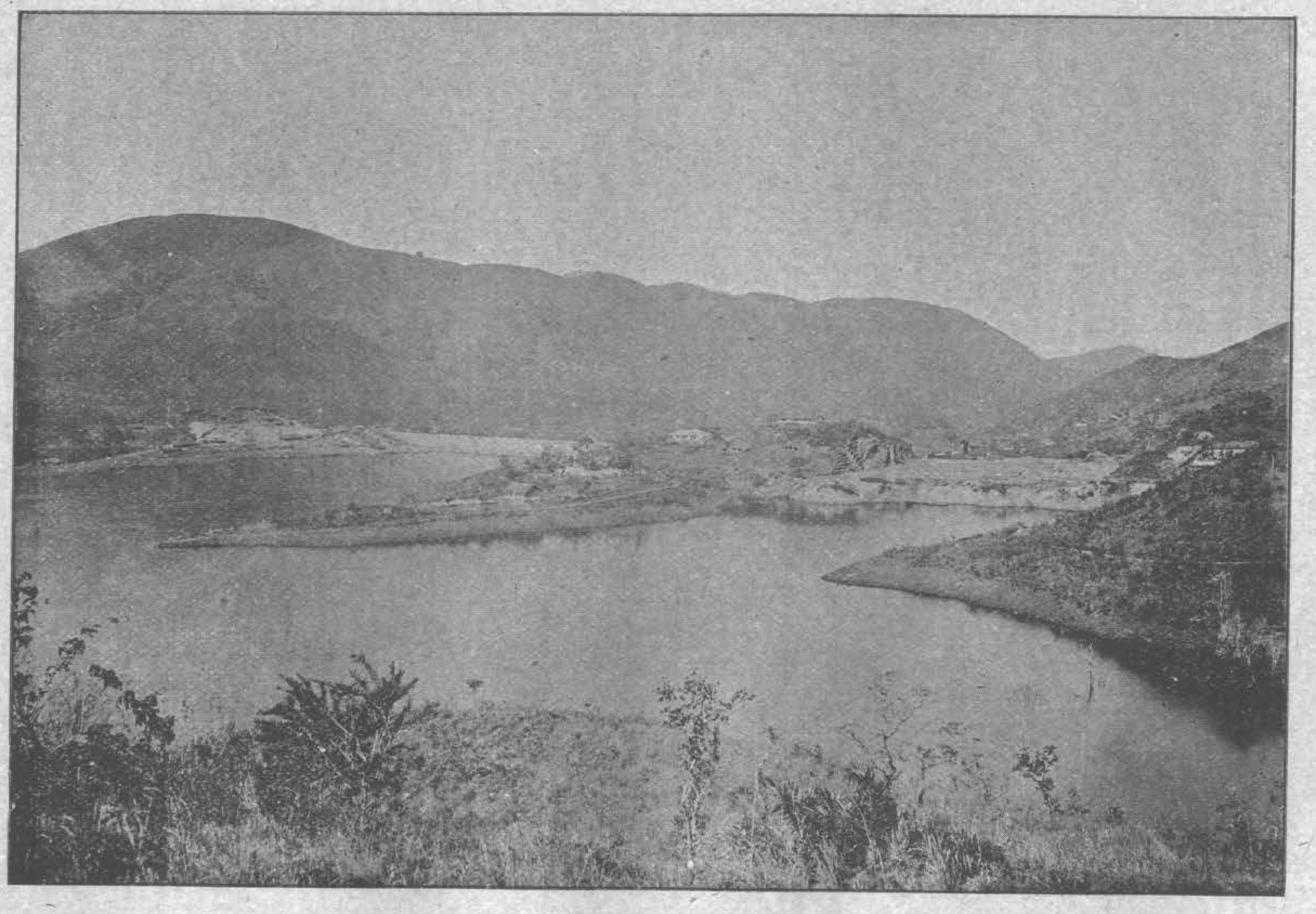


Photo.-Block.

Survey of India Offices, Calcutta, 1899.

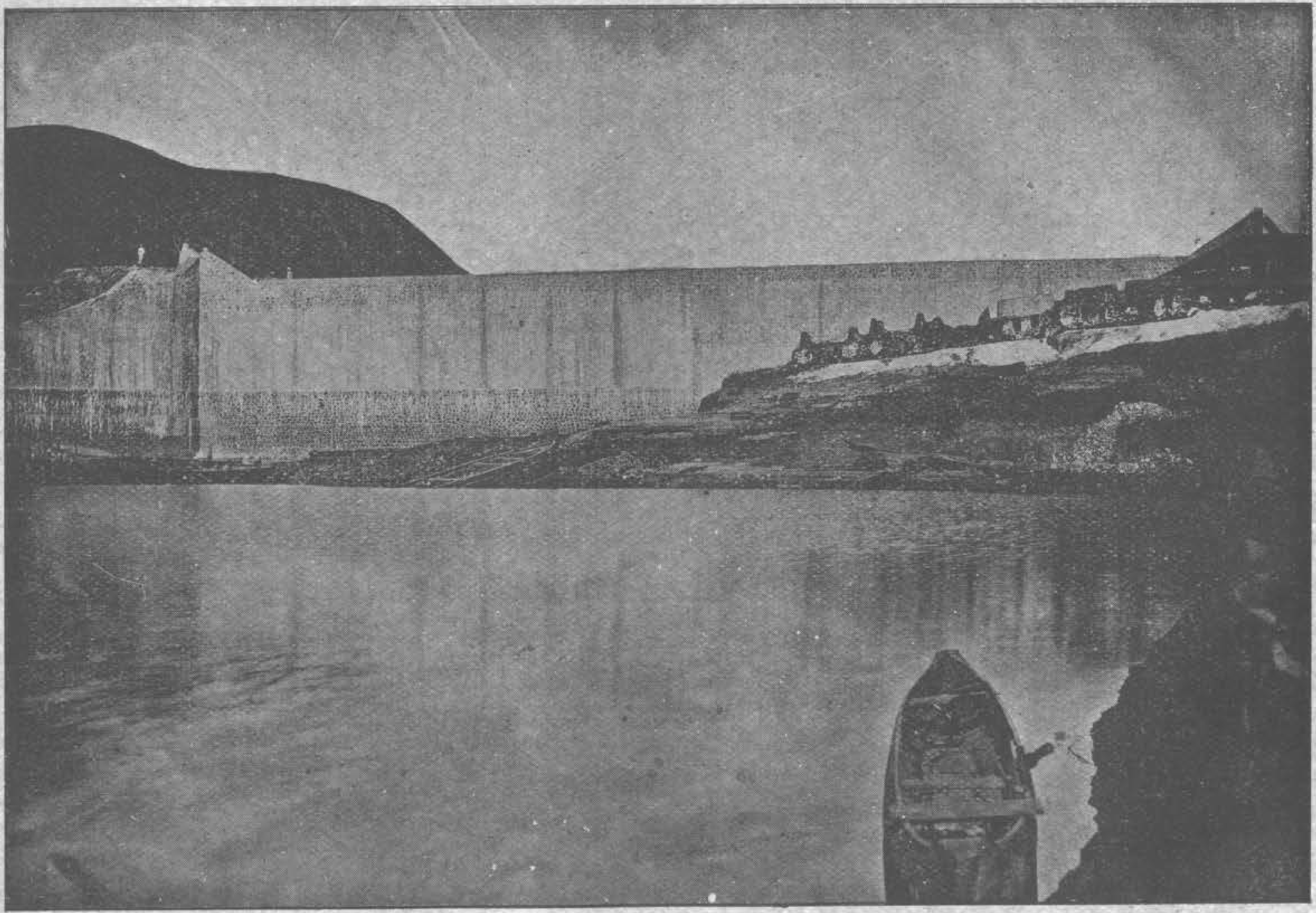
DAM AND RIGHT BANK ESCAPE, FROM UP STREAM.

to determine. The excavation for the foundation on both flanks was sometimes as much as 60 feet deep, and the sides have naturally in the course of time fallen in on the toe of the dam. The soil is never entirely free from moisture and the subsoil drainage flows down the rear toe of the dam, particularly on the left flank, and mingles with the real leakage. The total thus combined was in March 1896 gauged to be 0·18 cubic feet per second with the water level + 116 in the lake. In July of the same year with the water-level + 142 the measurement was 0·75 cubic feet per second, and in September 0·49 cubic feet per second with the same water-level. It clearly cannot be the case that the actual leakage decreased from 0·75 to 0·49 cubic feet per second in two months and the only possible inference is that the difference was due to the decrease in rainfall, June and July being specially wet months. August and September, though drier, are not free from rain, and a considerable quantity of water remains in the soil from previous rainfall, so that a further inference may be made that of the 0·49 cubic feet per second measured in September a certain proportion is due to subsoil drainage. March, on the other hand, is a very dry month and succeeds other dry months, so that the subsoil water is then very little; but though the measurement in that month was but 0·18 cubic feet per second the lake level was then at its lowest and the leakage would doubtless increase somewhat with a greater depth of water. On the whole, therefore, it is probable that the actual leakage through the dam varies between one-seventh and one-third of a cubic foot per second according to the level of the lake water, and a confirmation of this view is furnished by a subsequent measurement in February 1897, with W.L. + 130, which gave 0·26 cubic feet per second as the total leakage.

This amount is, of course, quite insignificant over an area of some 72,000 square feet, and would be so were it considerably more. The danger of such leakage is that it may carry out lime with it and gradually create a hollow in the interior of the dam. Analyses of the leakage water, in the hope of gauging the amount of lime in it, are from the circumstances very misleading. It is impossible to tell at what point of the front of the dam any particular leak begins and what course it follows. If it begins low down it probably carries in lime with it, since at the foot of the front of the dam there is a great accumulation of mortar fallen in the course of construction. The whole of the front and rear of the dam are also pointed and lime might easily be abstracted from the pointing. The course followed makes a large difference in determining the effect on the interior of the dam, since what would be a large amount abstracted in a short straight course becomes comparatively insignificant if the course is circuitous and long. In the actual bottling of samples for analysis also many chances of error occur, which, though small in each sample, become large when the amount is multiplied by minutes, hours, days and years. Nothing but a very large number of samples taken daily for a long period from carefully isolated leaks by an educated and intelligent operator could convey even an approximation to the truth, and even so the lowest sample would be more likely to be correct than the average. A truer and more satisfactory consideration is that all large dams leak, very nearly all leak more than the Periyár Dam, and no visible harm happens to them in consequence.

Left Bank Extension.

It will be seen from the cross section of the Periyár Valley that there existed on the left flank a depression, the lowest surface level of which was 116 feet above datum. This gap it was necessary to close, and on the supposition (supported by trial pits) that solid rock would be met throughout a little more than 20 feet below ground it was originally intended to build a dam across it to a level of + 144 and to use it as an escape for surplus water, a smaller wall below providing a water-cushion for the overflow. Compared with the main dam the total height (about 40 feet) was insignificant and it did not enter into the range of practical consideration, till the main dam should reach the level of + 100 or thereabouts. Shortly before this level was reached a beginning was made on the excavation for foundations in the depression, and the first results were very favourable, since on the right or northern flank and across the centre rock was exposed at a depth of from 12 to 20 feet below the surface of the ground. On the left or southern side however the rock began to dip and the excavation was found to consist at 20 feet depth of a slushy water-logged blue clay, mixed with large and small boulders. The sides slipped constantly on exposure to the air during wet weather. It was hoped that a continuance of fine weather would effect an improvement, but the exposed surfaces dried and cracked and fell down in large masses filling the bottom of the foundation trench and leaving behind them the same water-logged clay. The sides of the excavation were thereupon stepped back to 1½ to 1, necessitating a large extra quantity of earthwork ; but no doubt was



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Survey of India Offices, Calcutta, 1899.

LEFT BANK EXTENSION, FROM UP STREAM.

felt but that by perseverance rock would eventually be reached. The excavation proceeded slowly from January 1894 to September 1894, and in the latter month it was reported that it would in the ordinary course be completed about November, but could without difficulty be pushed to completion in a few weeks, should unexpectedly rapid progress on the main dam render this advisable. Rock had by this time been found at the bottom of the scarp or dip, and it was thought to be certain to slope upwards as it was followed in the southerly direction. In the next month October, it was reported that the lie of the bed rock was not so favourable as it promised to be, but there was no reason to apprehend any serious difficulty. Rock still trending downwards labour was increased and concentrated on the left flank, until the maximum depth of the excavation exceeded 50 feet, and the lie was admitted to be very unpromising and considerable difficulty was apprehended in the last few feet. The section was so different from that which had been exposed in every other case that it was regarded as a piece of nonconformable stuff that must soon come to an end, the more so that there was no definite evidence to denote a landslip, and the conformation of the immediately adjoining ridges made it appear most improbable that there could be much more downward trend. Work proceeded with great trouble from slips till March 1895, when it became evident that rock would not at any rate be reached during that month. The main dam was now rapidly approaching the level of + 115, and it would be necessary in the next monsoon to expect the rise of the lake to a similar level. It was, therefore, decided to isolate the left flank by a protective combination of masonry and earthwork, with vents to pass the water when the lake rose; but it was still hardly doubted that before July rock would be found and masonry built in.

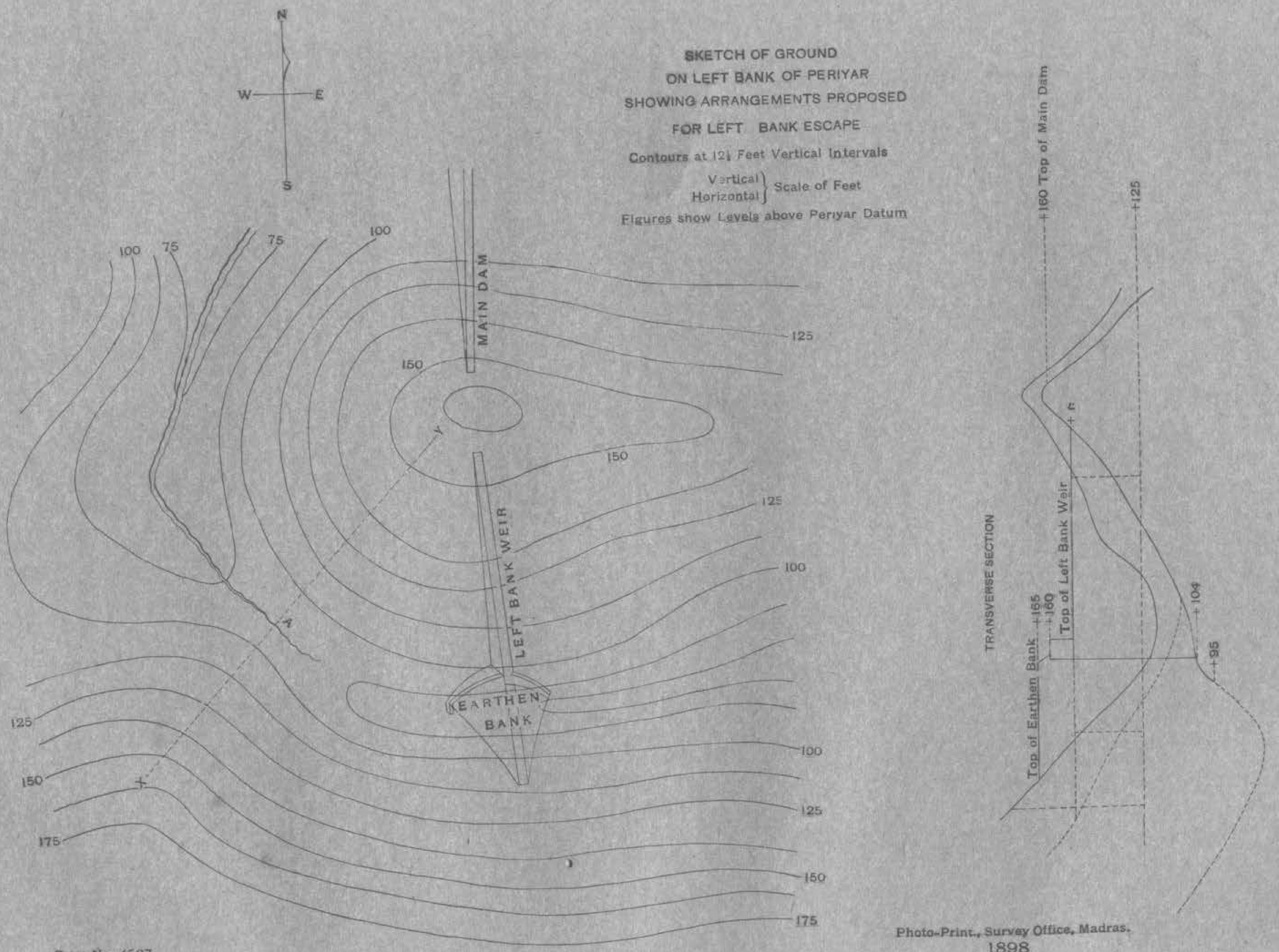
In April 1895 the Chief Engineer visited the works and took a more unfavourable view as to the prospects of rock being reached within a reasonable time and reasonable expense. He, therefore, decided on a change in the plan of construction, which is detailed in the following note on the subject, which though it involves a small amount of repetition is here extracted in full, in order to give a clear account of the situation:—

" On each bank of the river the main dam abuts upon a low hill, which on the side furthest from the river falls to a short saddle, from whence small tributary streams run in each direction joining the main river above and below the dam; and the ground then rises to a high range of hills several hundreds of feet above the river bed. The formation is precisely the same on both banks except that on the right bank the small hill and the saddle between it and the main range are higher than on the left. It was intended to use both these saddles as escape weirs, that on the right bank being cut down and that on the left built up to the required level.

"On both banks of the river and on the right bank saddle the anticipations based on the original surveys were fairly well realised, rock being found at varying, but on the whole moderate depths below the surface soil, and there was every reason to believe, that similar conditions would obtain on the left bank saddle. This expectation was realised at first, the excavations showing rock at about the depth expected all along the south slope of the hill on which the left flank of the dam rests down to the saddle itself on which rock was found for some distance at a level of 104 feet above datum, exactly the level shown in the sections attached to the original estimates. Here, however, the agreement between expectations and results ends; instead of rising towards the hill on the south the rock falls somewhat abruptly.

"The continuation of the excavation beyond this point has been a matter of some difficulty, as the hill above is so steep that the earth is constantly slipping and we have had to do an amount of excavation out of all proportion to the area of rock exposed. The latter has been followed down to a level of about + 95, and it is by no means certain that we have yet got to the bottom of the dip, while it is quite certain from the excavations that have been made higher up the hill that a very heavy amount of earthwork has yet to be done before there is the least chance of finding rock at the level required for a continuous masonry dam across the valley. The accompanying plan and sections (Plate XI) show the features of the ground and the position of the rock as far as we have yet discovered it; the latter is shown by the coloured portion on the section, while the fine dotted line shows the position in which it was expected to lie.

"It is by no means certain what is the cause of this peculiar formation; it may be due simply to a fault in the rock, and this was the view to which I was for some time inclined. If this is so, the fault is a very deep one, and we do not know that we have yet got to the bottom of it. I am however now inclined to the belief that there is no fault at all, but that the line on which we have been excavating is not the true (or rather the original) dividing line between the tributary streams, the spur on which we have been working being caused by a landslip. A little to the west of this spur there is a second one which is certainly due to this cause; further west there is still a third spur along which (about on the line XY on the plan) an excavation has been made which discloses rock at a moderate



SKETCH OF GROUND
ON LEFT BANK OF PERIYAR
SHOWING ARRANGEMENTS PROPOSED
FOR LEFT BANK ESCAPE

Contours at 12½ Feet Vertical Intervals

Vertical } Scale of Feet
Horizontal }

Figures show Levels above Periyar Datum

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1898

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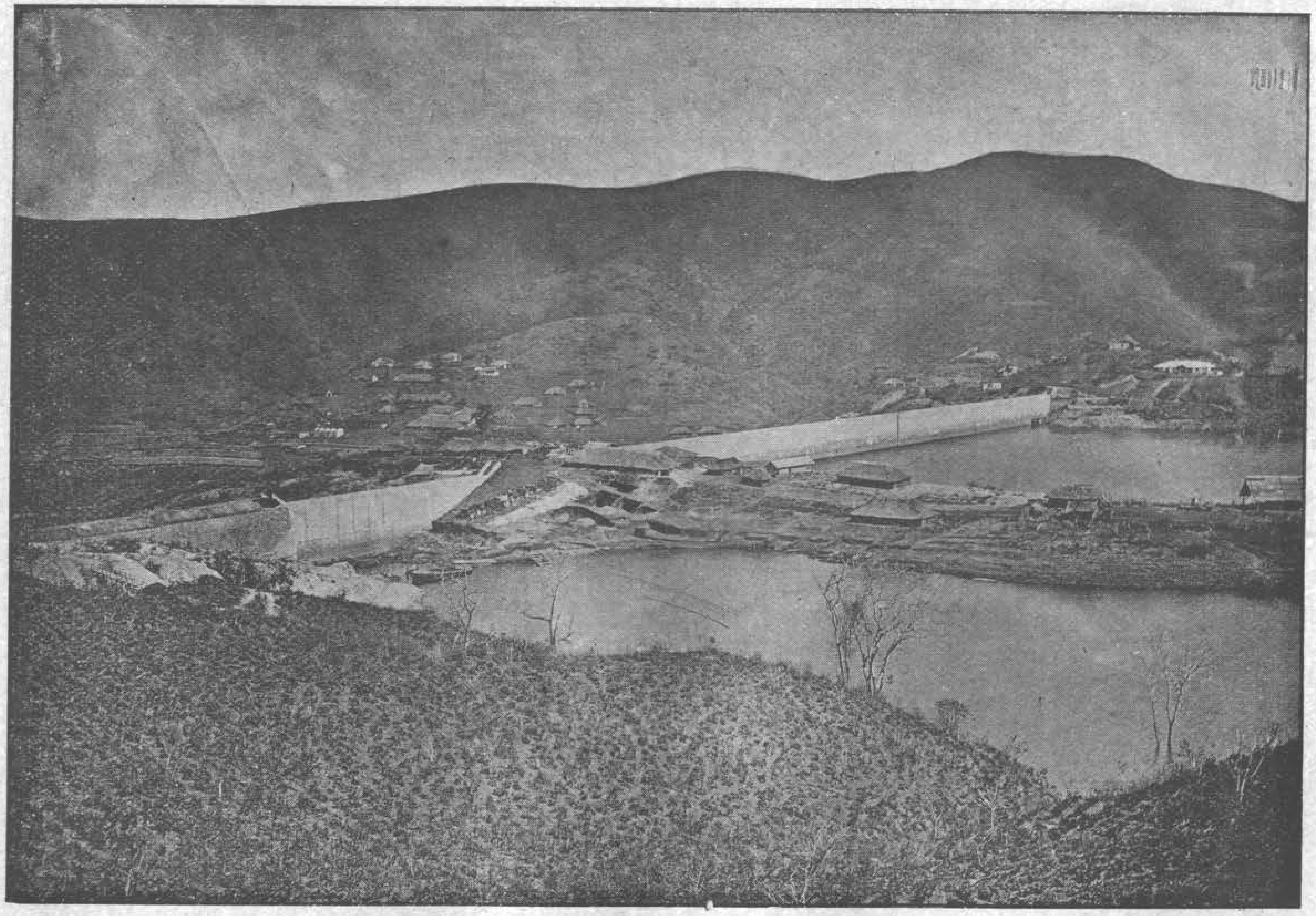

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Survey of India Offices, Calcutta, 1899.

DAM AND LEFT BANK EXTENSION, FROM UP STREAM.

depth right across the bottom of the valley, its level at the lowest point being about + 88; the rock has been followed on the southern side of the valley up to about + 120, at which point there is a somewhat extensive fault, and it has not been considered advisable to follow the investigation further, as it is clear that nothing would be gained by following this line. I am inclined to think that the original dividing ridge between the two tributary streams was somewhere about this line, the contours running somewhat as shown by the tracing attached to the plan, and that the present formation is due to an extensive slip from the hill above which has blocked the original eastern valley and diverted a portion of its waters to the west. This view is confirmed in some measure by the existence of a rather extensive swamp round the point A on the plan. If this view is correct, the rock on the line of the present main dam must descend to somewhere below + 80 and probably runs somewhat as shown by the thick dotted line on the section. In this case the most favourable line for a dam to be founded on rock throughout would be about XY, but even if the fault previously mentioned is not an extensive one, the cost of a dam entirely of masonry on this line would probably not be less than Rs. 2,50,000 and might be a good deal more.

"It is therefore proposed to take advantage of the favourable position of the rock on the northern portion of the original line to build on this as far as it goes, and at the point where it begins to fall to construct a massive wing wall which will support an earthen bank connecting the masonry dam with the hill beyond. The front portion of the wing wall is now under construction, and before the water rises sufficiently to pass over the saddle will be completed to a level of + 125, which is sufficient to prevent the flank being turned as long as the masonry portion of the dam remains at its present level. Next season the wing wall and the earthen bank behind it will be raised in due proportion with the remainder of the work. The masonry wall has been carried right across the valley to a height of + 116 (2 feet below the main dam) with three vents 10 feet wide near the southern end, their sills being at + 110; these will pass the ordinary discharge of the river leaving the main wall for the passage of high floods; the work on the main dam will thus proceed without interruption, the left bank dam being raised from time to time as may be desirable. It may be noted here that the front wing wall runs into natural ground at a level of + 135, so that the embankment is only exposed to water above this level, and the maximum flood level being + 155 (or probably a couple of feet less) the greatest depth of water against the bank is only 20 feet.*

---

* Supposing that no water leaks through or round the end of the wing wall at a lower level.

"As far as I can judge at present the arrangement contemplated will cost little if anything more than the original proposals, while it is entirely free from any element of risk or of difficulty requiring more than ordinary precautions. It would have been slightly cheaper to have closed the valley throughout with an earthen bank, and had the position of the rock been known sooner it might have been worth while to adopt this course, but as matters are now it will be a great convenience to use this saddle as a temporary escape during the first part of next season, and it would not be worth while to give up this convenience except for a much greater saving than is likely to be effected. This plan would have had the disadvantage of not permitting the saddle in question to be used as a permanent supplemental escape; the disadvantage is not a very serious one but has a certain amount of weight."

On this plan the wings were at once begun and a commencement made in refilling the excavation. Abnormally heavy rain early in June flooded the foundation trench before it could be refilled with dry earth, a difficult process in any case on account of the leakage from the sides. The water was displaced by throwing in earth in the deepest part up to its original ground level, which allowed the rain to run off, but there were still numerous springs from the water-logged clay which continued running even when covered with earth. These were, therefore, led into drains of hand-packed stone and conducted through the commencement of the rear wing wall into two 10-inch wrought-iron pipes. When the weather became drier the drains were covered with sacking and the earthwork proceeded in layers in the usual manner.

The water in the lake rose to the level of the vents at + 110 early in July and stopped work for the time being, but as soon as the force of the monsoon diminished towards the end of August the vents were closed without difficulty and work was resumed. An examination of the foundations of the rear wing then disclosed that the fault previously described, which had put a stop to the southerly extension of the masonry body wall of this dam, curved round in a north-westerly direction instead of running due west, and therefore intercepted the line of the intended wing. This compelled the abandonment of the idea of using this portion of the work as a permanent escape, for though the wall itself was on perfectly sound rock the fault was so close to its foot that it was not safe to allow water to fall on it from a height of 40 feet or more. It became therefore unnecessary to build the rear wing wall

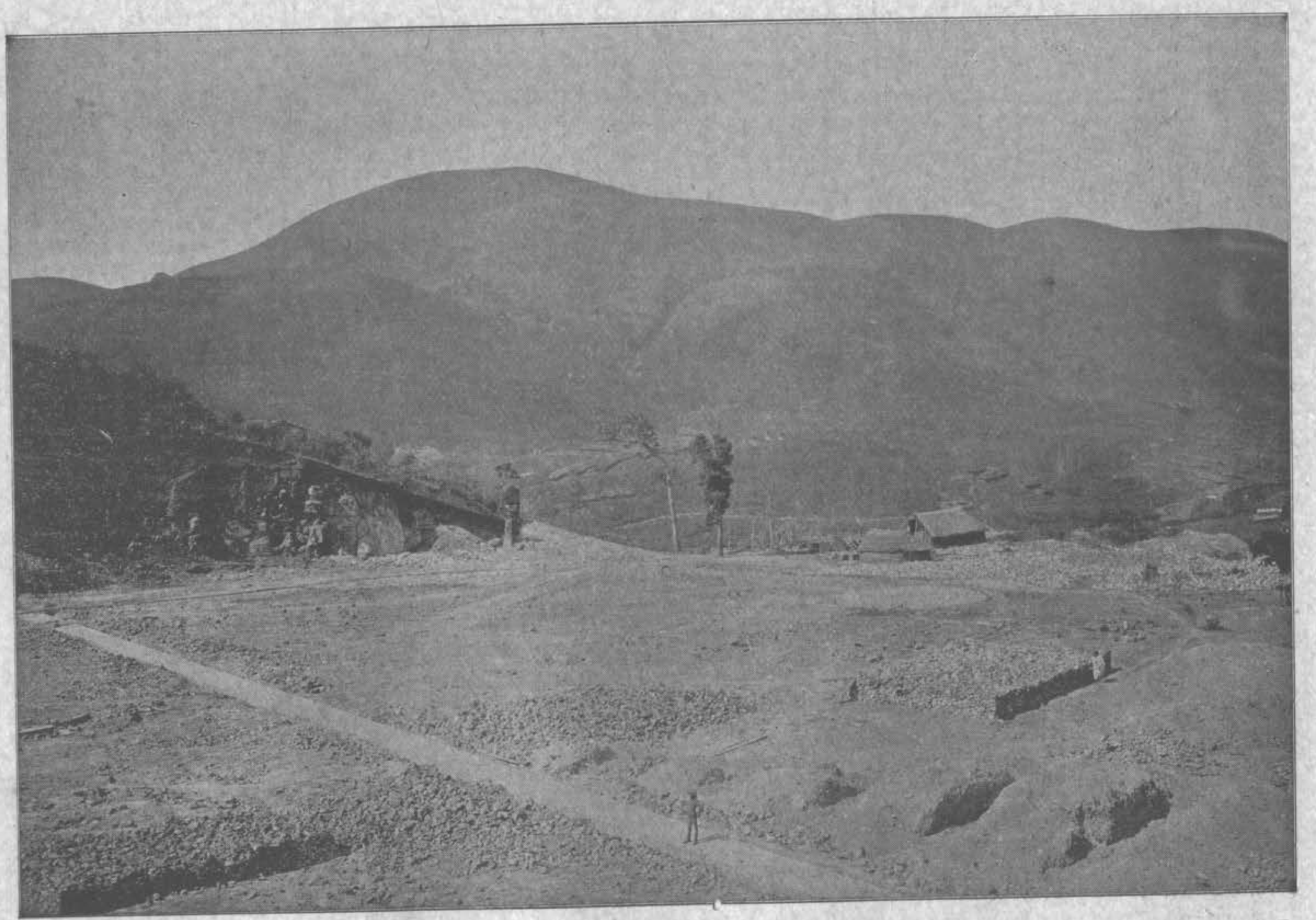


Photo-Block.

Survey of India Offices, Calcutta, 1899.

RIGHT BANK ESCAPE.

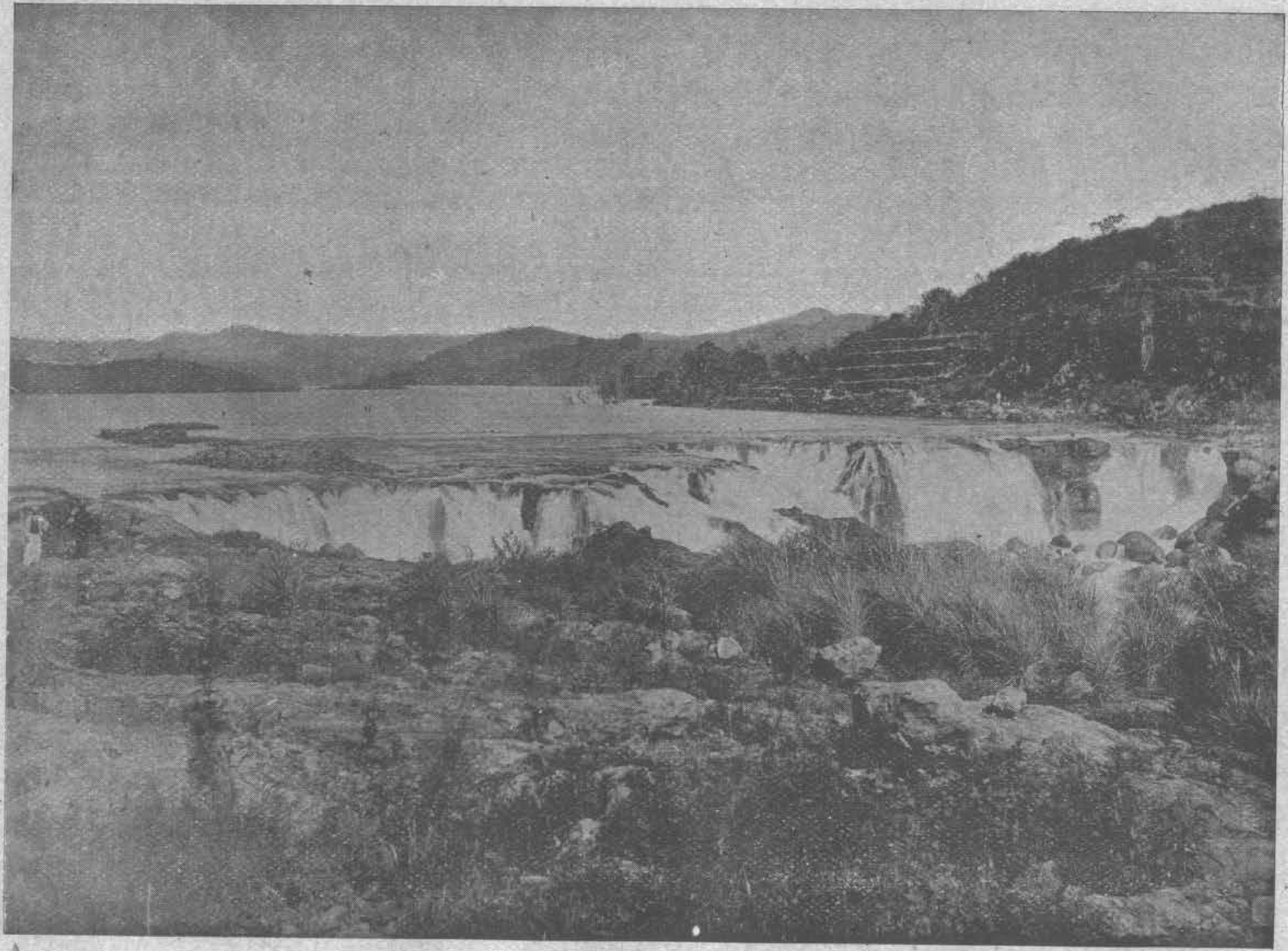
to the earthern bank at the south end and the bank was allowed to assume its natural slope in rear. In front, above the wing, the bank was heavily revetted, and turfed in rear. The work was completed in February 1896, the earthern bank on the south being taken up to + 166 with a top width of 12 feet. The masonry body wall was in section and structure similar to the main dam, but the top of the parapet was taken up to + 160.

Right Bank Escape.

In chapter I, reference is made to the two permanent escapes which it was proposed to construct, both with a crest level of + 144. It has already been described how it became necessary to completely fill the saddle on the left flank and transform it into a dam, thus abandoning it as an escape. The saddle on the right flank alone remained, which was cut down to the proposed level for a length of 420 feet, thus diminishing the available length from 900 feet to 420 feet. It was impracticable to materially extend this length, since on the south the rock dipped below the + 144 level, while on the north the ground rose rapidly and necessitated an inordinate depth of cutting. An extension to the south would have involved massive and expensive wings and would moreover have tended to direct the surplus flow towards the rear toe of the main dam. A northern extension might have served as a quarry, but the rock was very deeply overlaid with earth which would have cost large sums to remove, while there were many more favourable situations for procuring stone.

The length provided however (420 feet) is by calculation just sufficient to prevent the main dam parapets from ever being topped. During the construction of the works the highest flood gauged 30,000 cubic feet per second, and Table V gives the quantities observed during the investigation from 1869—1873 inclusive. It will be noticed that one of these floods very far transcended all the others and there is evidence that no flood approaching it in magnitude can have taken place for fifty years at least. This flood, amounting to 127,000 cubic feet a second at its maximum, has been taken as the greatest for which it was necessary to provide. The duration and rise of this flood were observed when it occurred and are detailed in the table below, which shows the proportionate rise of the lake during its continuance :—

Level of lake surface.	Discharge from lake.			Discharge of river.	Stored in lake.	Capacity of lake.	Time in filling.	Total duration.
	Tunnel.	Escape.	Total.					
Feet above datum.	Millions of cubic feet per hour.				Millions of cubic feet.		Hours.	Hours.
144–145 ...	6	2	8	130	122	280	2·27	
145–146 ...	6	7	13	130	117	285	2·44	
146–147 ...	6	14	20	130	110	289	1·79	
								6·50
				209	189	...	·48	
147–148 ...	6	22	28	...	181	294	·52	
								1·00
				243	215	...	·93	
148–149 ...	6	32	38	...	205	298	·07	
								1·00
				272	234	...	1·00	
								1·00
				294	256	...	·19	
149–150 ...	6	44	50	...	244	300	·81	
								1·00
				291	241	...	·42	
150–151 ...	6	56	62	...	229	306	·58	
								1·00
				251	189	...	·90	
151–152 ..	6	70	76	...	175	310	·10	
								1·00
				200	124	...	1·00	
								1·00
				153	77	...	1 00	
								1·00
				118	42	...	1·00	
								1·00
				105	29	...	1·00	
								1·00
				118	42	...	·47	
152–153 ...	6	84	90	...	28	315	·53	
								1·00
				315	225	...	1·33	
153–154 ...	6	100	106	...	209	320	1·53	
154–155 ...	6	116	122	...	193	325	·64	
								3·50
				531	409	...	·49	
155–156 ...	6	132	138	...	393	330	·51	
								1·00
				516	378	...	·34	
156–157 ...	6	150	156	...	360	335	·66	
								1·00
				457	301	...	·32	
157–158 ...	6	169	175	...	282	340	·68	
								1·00
				309	134	...	1·00	1·00
				150	–25	Falls.		



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Survey of India Offices, Calcutta, 1899.

RIGHT BANK ESCAPE.

Assuming the most unfavourable conditions, viz., that the maximum flood began when the lake was already full, it will be seen that the water ceases to rise just before the level of the top of the parapets of the main dam is reached, that is at a little below + 158 ; and even if the flood attained 9,000 cubic feet a second more, an almost impossible apprehension, the dam would still not be topped by more than a foot, which would be most unlikely to cause any appreciable damage, and certainly no danger.

The actual formation of the escape needs little description. A gullet was first driven through it from east to west in order to allow a passage for a tramway and for the road from Tékadi to the cooly-lines and bazaar. This gave six faces to work at, but as the stone was all required for the main dam and there was but little storage room progress was restrained to the requirements of the dam. The rock turned out to be more than originally anticipated, as shown on the sections, Plate VIII, but there were no hindrances except occasional slips on the north face where the scarp was very high. The work was finished by the end of 1894, the total quantities removed being—

	CUBIC FEET.
Earth and soft rock	9,795,630
Rock	2,215,508

The principal explosive used was gelignite, and as it was found economical to blow the stone small enough to be easily handled and to be fed into the stone-breakers, the average outturn was about 85 cubic feet per lb. of explosive.

Cutting and Tunnel through the Watershed.

The passage through the watershed may be treated as including (1) an open cutting or approach 5,342 feet long on the south side, (2) a tunnel 5,704 feet long, and (3) an open cutting or debouchure 500 feet long on the north side. The longitudinal section is given in Plate V.

The cutting on the south or Travancore side, which was known as the watershed cutting, consisted of 3,000 feet on the level, with bed at 115 feet above datum, and 2,342 feet with a fall of 1 in 320, the bottom width being 21 feet throughout, the sides vertical in rock and with slopes of 1½ to 1 in earth. It was a straightforward if tedious piece of work, the principal trouble experienced being with the Mulya Panján, whose course crossed the line at several points and had to be trained and diverted, but which occasionally broke in and deposited a good deal of

As each section of the cutting was finished, working northwards, it was included in the canal, which thus eventually reached the tunnel entrance, which was also the terminal of the over-head wire ropeway up the ghaut. The excavation consisted of earth and rock. The latter was done throughout by hand, machine drills worked by manual labour having been tried at first without much success.

The total quantities of earth and rock removed were—

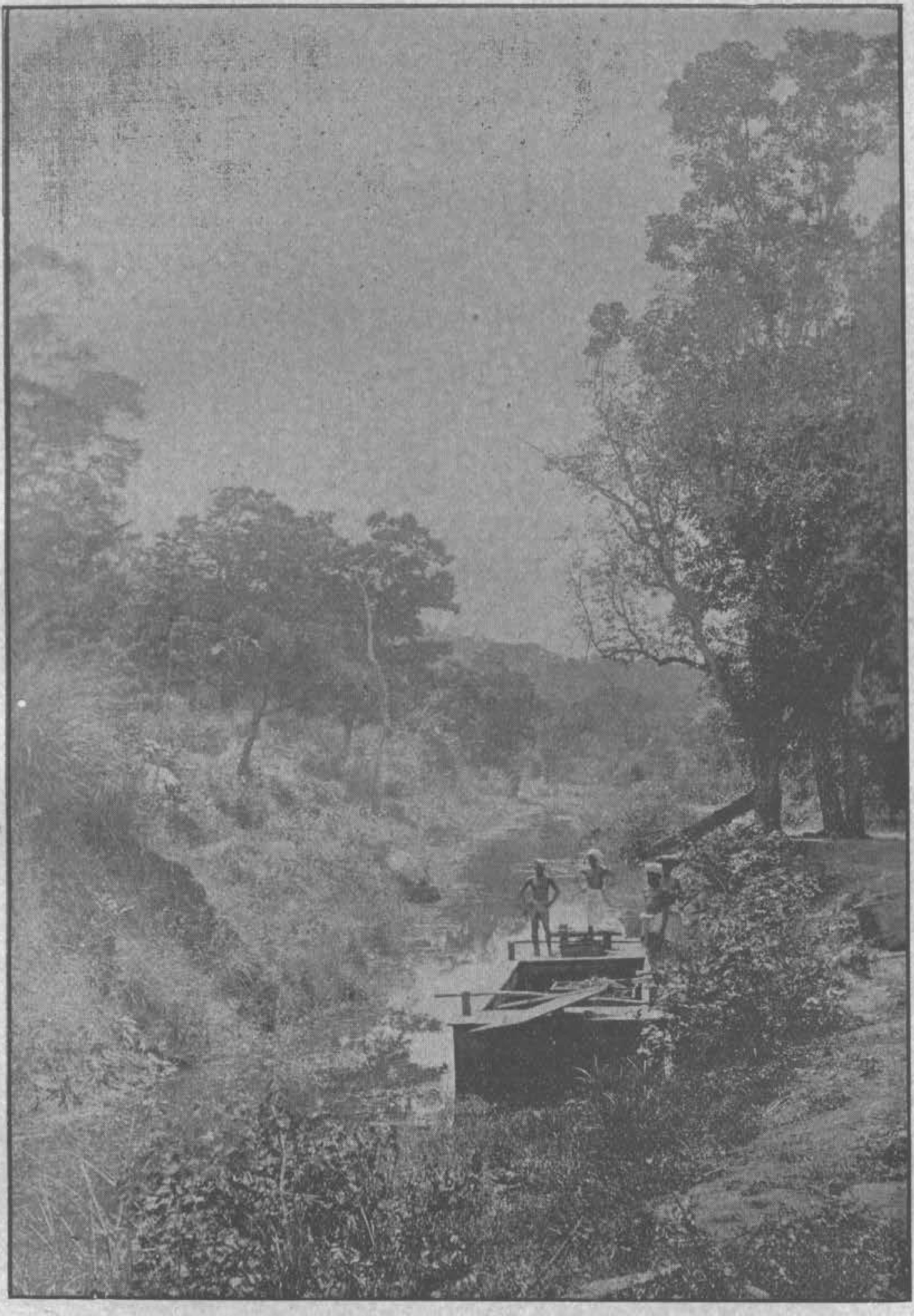
	CUBIC FEET.
Earth	2,217,120
Rock	633,731

It had been intended to load the stone, as it came out, into boats and convey it direct to the main dam for use in the masonry. This, however, presupposed an easy means of transport from the commencement and as elsewhere related the canal was very far from fulfilling this condition; and the cost of transport was so great that even with uninterrupted water-carriage to the dam—and much more when the canal did not go the whole distance and was also frequently out of order—it was found extravagant to attempt to utilise this stone. It had, therefore, to be deposited on the banks, and the lift and lead, want of space, and extra handling added materially to the estimated cost of the cutting.

It will be seen from the longitudinal section that the depth of cutting, and especially of rock, increased northwards, but just before it met the tunnel there was a dip in the rock, while the ground level began to rise rapidly up the hill. This dip caused some trouble, since the cutting was at that place nearly 50 feet deep and the sides of clay, which became slushy on exposure to water and slipped constantly. The sides were sloped to 1 to 1 but still refused to stand, so eventually a strong toe-wall was constructed. This also was thrust out and had to be replaced by one still more massive.

The rates for excavation on this cutting are given in the appendix.

The other cutting, 500 feet in length, from 0 to 20 feet in depth, was the outlet to the tunnel on the Madura side, and was also 21 feet in width with a fall of 1 in 250. It was completed before the tunnel proper was commenced, and consisted almost entirely of rock, of which 158,095 cubic feet were removed. It debouched into the ravine or natural torrent bed by which the Periyár water now finds its way into the Vairavanár and thence into the Suruliyár and the Vaigai.



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WATERSHED CUTTING.

The tunnel proper has a section 12 feet wide by 7½ feet high and a gradient of 1 in 75. On account of the steepness of the gradient it was at first decided to work only from the northern or Madura side, in order to avoid pumping, and a road about a mile in length was accordingly made taking off from the trunk road in the 46th mile from Periyakulam and leading to the lower end of the outfall cutting. Here the air compressors were installed and the turbine by which they were driven. A small reservoir had previously been made by blocking up a swamp which lay almost on the watershed line and received a considerable drainage during the rains. This reservoir was bounded on one side by hills and on the other by the trunk road which ran across the natural drainage line on swampy ground and served as a bank. At a later period, when the water in the reservoir was found insufficient, the road was raised, but the foundation was so bad as to occasion much care and trouble, causing breaches more than once during heavy rain and sometimes serious damage. It was impossible therefore ever to store enough water in the reservoir, and as both the tunnel north end machinery and the wire-ropeway up the ghaut were dependent on it, they were always obliged to stop in January at latest and sometimes earlier, while no water could of course be spared to keep up the canal in the dry weather.

From the reservoir a channel, nearly two miles long, was led to the turbine, partly in an existing channel, but mostly new, either in open cutting along the sides of the hills, or (where the lie of the ground was very steep and across the numerous small ravines) in a wooden flume supported on piles. This channel also gave considerable trouble. The flume was at first made much too slight, and on account of the paucity of labour and the steepness of the hill sides, the cutting was not everywhere taken deep enough into the hill. The bridges across the ravines were also insufficiently strong. It served however for the time being to take water to the turbine, and the machinery, in which several defects were found, was tried and adjusted, and some progress made with the tunnel while the defects in the channel were being remedied. The reservoir and turbine channel cost in all over Rs. 25,000, excluding ordinary maintenance.

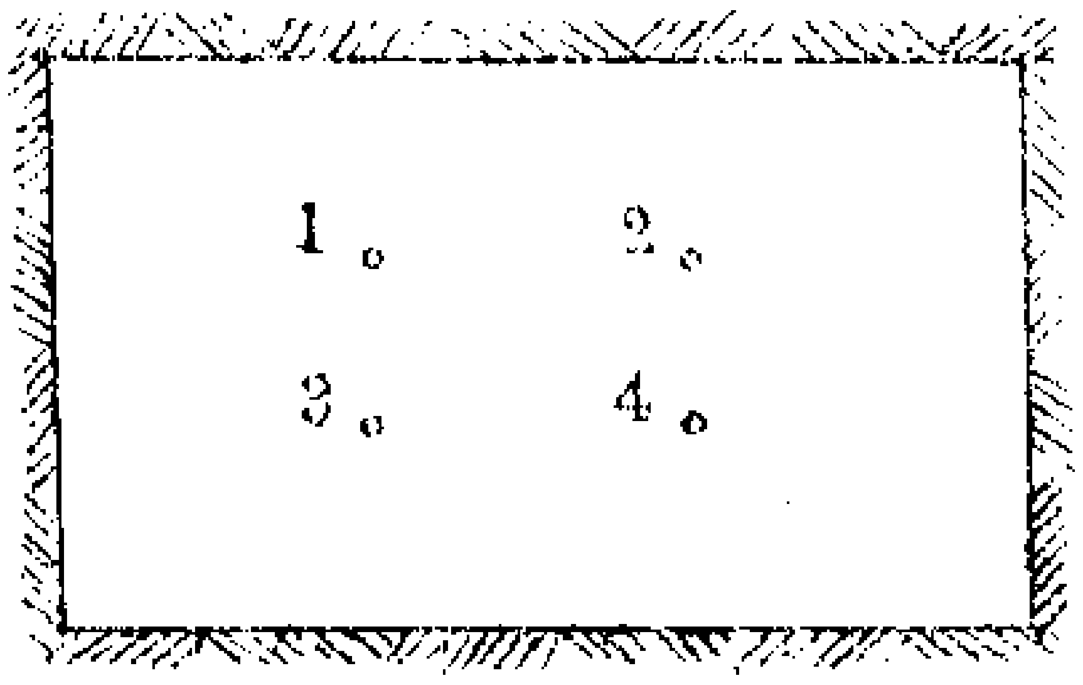
The penstock and strainer were built immediately over the turbine, which received the water through 10-inch wrought iron lap-welded pipes, with flanged joints, bolted together with India-rubber washers. The total available fall was 157½ feet. The turbine was of the horizontal radial flow type, to develope according to specification 50 H.P., but owing to a mistaken system of lubrication and careless setting of the guide blades and buckets the power was never obtained. The compressors consisted of two 16-inch double acting cylinders fitted with inlet and outlet valves at each end, with pistons of 24-inch stroke, driven off two cranks at an angle of 90° on the same axle. The pulley was very large and heavy, to act as a fly-wheel, and was driven by spur-gearing by means of a counter-shaft, with a belt from the turbine shaft. The cylinders were water-jacketed. The air was discharged into two receivers, the specified pressure being 45 lb., but it was never maintained continuously at much more than 30 lb. with all the piston-duty, and if all the drills were working at the face one set of valves was generally thrown out.

The compressed air was led to the face in 4-inch wrought-iron flanged pipes, bolted together with India-rubber washers, and laid in the side drain, in which a little water was always running. The result was a distinct drop in pressure at the face, but the atmosphere in the tunnel was kept cooler. The air was distributed to the drills by flexible pipes from the end of the common air pipe. The drilling machines were originally mounted on wheeled carriages, but these were quickly discarded, one trolly alone being kept to run the machines in and out. During drilling the stretcher-bars were wedged against the roof and the floor and did not need to be moved. The drill-pistons were, as usual, carried on cradles traversing on the stretcher-bars and the drills used were from 2½ inches downwards, with taper attachment, and bits varying according to circumstances. The specification was that the plant should be capable of drilling holes sufficient to take out 7 feet length over the whole area of 12 feet by 7½ feet in a 9-hours day, but owing to the insufficiency of the turbine this quantity was never reached, a good day averaging 4 to 5 feet.

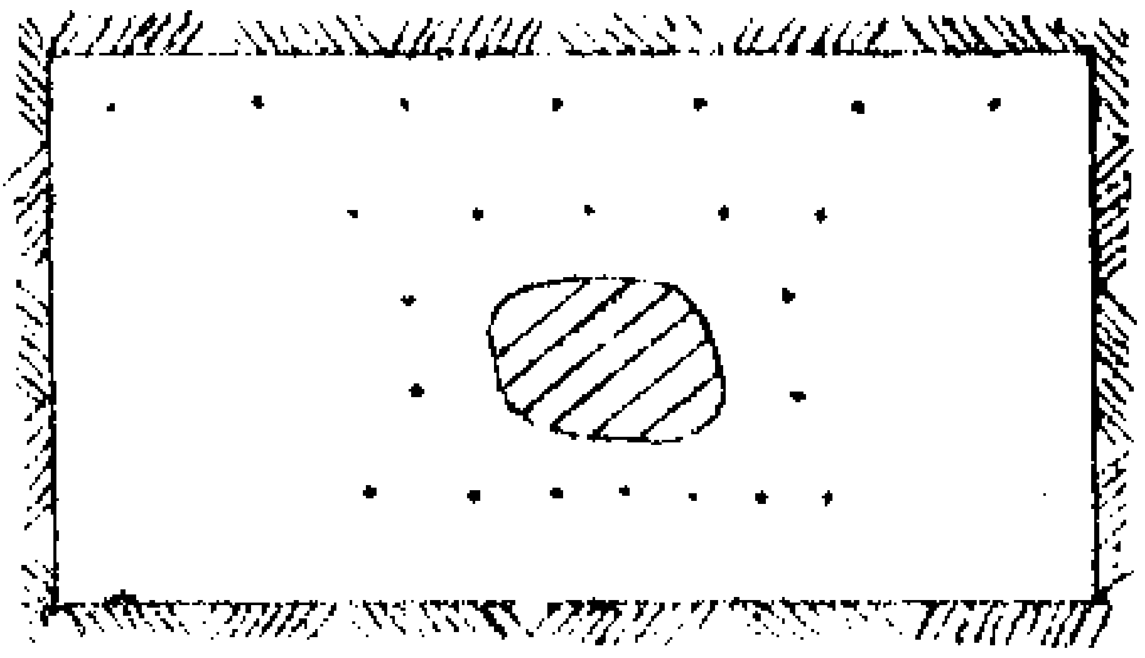
The tunnel was throughout in granite, grey, blue or red, the latter being particularly tough to drill, while all were hard, but blew well. After due experiment the best explosive was found to be blasting gelatine and this alone was used. Electrical firing was at first tried and gave good results, but was uncertain; and in case of a misfire the time lost in going over the connections upset the whole arrangement of shifts. Accordingly Beckford's instantaneous fuse was thenceforward always employed.

All the holes were drilled in one shift, about nine hours being required if the machinery was working smoothly.

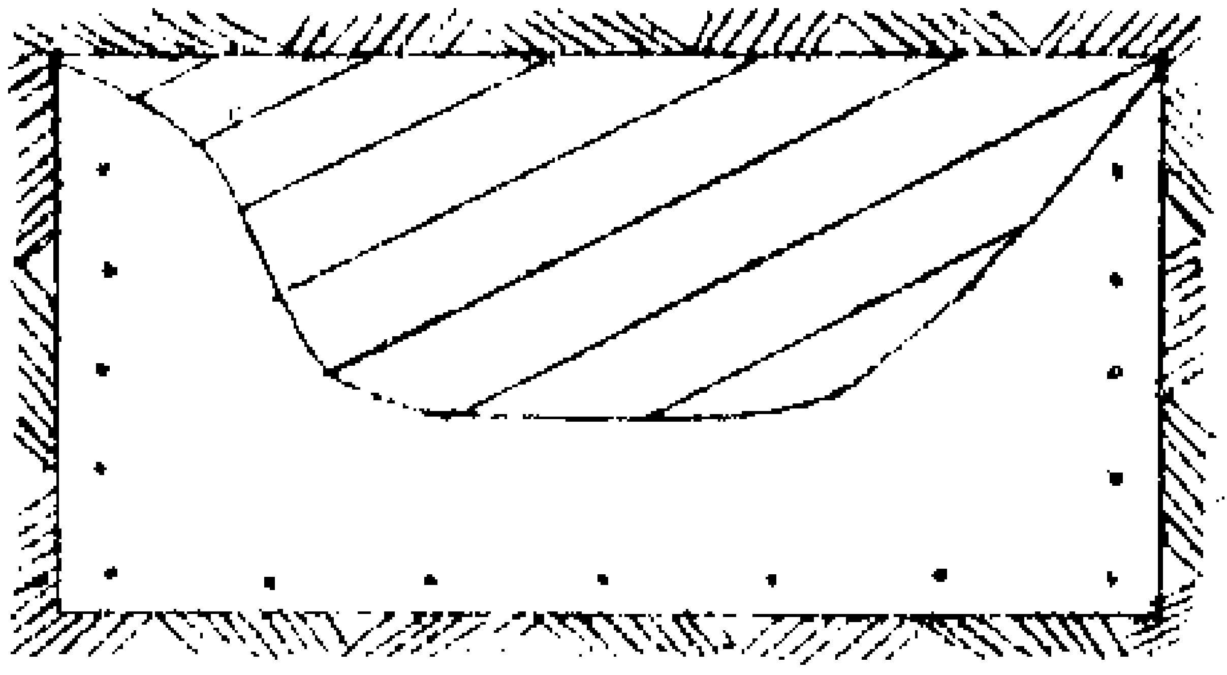
They were begun with the 2½-inch drill and finished generally with a 2-inch, and the machines were then run back about 1,000 feet. The holes marked



1, 2, 3, 4, constituted the centre cut and were from 6 to 7 feet long, converging towards the centre of the section. Five pounds of gelatine, rammed in with a wooden rammer, and well-tamped with dry clay, was the charge for each of these holes and they were fired first and simultaneously. Next the holes 5 to 25 in number,



at the top and round the centre cut were fired; then the side holes and lastly the bottom holes, the two



latter averaging together about 20 in number. The charge for each hole varied according to the character of the rock and the condition in which previous blasts had left the face, but generally from 40 to 50 lb. of gelatine was used beside the centre cut. It was most essential that the blast should not be insufficient, since that entailed bringing in the drills again and upset the rotation of shifts. The side, top and bottom holes, were drilled diverging slightly outwards, so as to ensure their taking out the whole section, and the section as completed is actually about 6 inches larger in each dimension than designed. The time taken in firing was generally about 3 hours, a certain amount of spoil having always to be cleared before the bottom holes could be fired.

Removing the spoil occupied about 12 hours, and as it was advantageous to have day light at the tip, the drilling was always done at night. A single line of 2½ feet gauge, with crossings and sidings, was laid as the tunnel advanced, with iron sleepers on a bed of ballast. From 6 to 20 wagons of half a cubic yard capacity, and from 25 to 80 men, were required according to the lead, the wagons running out by gravitation and being drawn up in trains of four by ponies. The stone had to be blown very small at the face, as the coolies were quite unequal to handling anything heavy. At the face two men were needed for each drill, and two blacksmiths and a fitter were kept constantly employed. For all in the tunnel a shift was 8 hours and overtime was paid for at the daily rate. Outside the tunnel a shift was 9 hours.

Ventilation was effected by an exhaust fan with a capacity of 1,000 cubic feet per minute situated close to the mouth of the tunnel and driven by a 6 H.P. turbine on a fall of 120 feet of the same type as the compressor turbine. The flue was made of 1-inch planking 3 feet square plastered with clay at the joints, over which battens were nailed. There was a delay of about 15 minutes after each blast before the atmosphere became bearable. During drilling the exhaust from the drill-cylinders kept the air at the face fairly pure and the fan was not always required.

The preliminary work, construction of road, reservoir, turbine channel, installation of machinery, occupied till October 1889, by which time the open cutting at the north end was finished and a few feet of the tunnel proper had been driven by hand. The alignment on the ground had also been completed, first roughly by a chain and compass survey taken round by the road, then more accurately from repeated observations from marks on the crests of the ridges with an omnimeter. This enabled a back sight of 120 feet in length to be obtained by fixing points over the tunnel exit and in the outfall cutting, the error of which could not be very large and was at any rate parallel to the true line. Afterwards, when the line from ridge to ridge had been cleared of jungle, it was accurately measured on the ground and checked, but the error was infinitesimal. The lining in the tunnel itself was continued by boning rods hung from the roof and checked from time to time with lights and a theodolite. To anticipate slightly, the deviation in the horizontal plane was on completion found to be less than 2 inches and in the vertical plane nothing. The exact length was 5,704 feet. In November 1889 drilling by machinery at the north end was begun and a fairly steady progress of about 4 feet per working day maintained. This rate could not be increased and by April 1891 the total advance was only 1,008 feet and it had already been determined to employ other means to accelerate it. A shaft, known as No. II shaft, was therefore sunk on the line at 4,146½ feet from the north end and 1,557½ feet from the south end. This shaft measured 14 feet by 7 feet, and was 109 feet deep. A second-hand steam plant was purchased and erected near the shaft consisting of 3 Root's boilers 15 H.P., with a horizontal engine and compressor, and a 3½-inch rock-boring machine. A winding-engine and pump for the boilers were also fitted up and these had shortly to be supplemented by a pump in the shaft and a winch and cable for hauling loaded trucks on the upgrade. In order to take out the full section drills considerably larger than the plant was designed for were used, and a large addition to the boiler-power was therefore required and was supplied by portable engines which were at hand on the works. Ventilation was effected by a diaphragm down the shaft connected at one end to a flue and at the other to the fire-boxes of the boilers, and by running the compressors with the drills detached after blasting. This plant began working both southwards and northwards in alternate shifts, the number of men for removal of spoil being between 30 and 50; and this was continued till April 1893, when on account of the difficulty of pumping work on the north face was stopped. Up to this time the advance was about 2 feet a working day on each face from the shaft, and the total advance on all faces combined was 3,600 feet. From this time work at No. II shaft was confined to the south face until it was nearly through in November 1893, when it was stopped and work on the north face resumed until February 1894, after which the work was completed from the north end alone. A partition was left at the south face on No. II shaft until work northwards was stopped, in order to prevent an inflow from the Muliya Panján, and this was left until February 1894. The other two faces met accurately in October 1894.

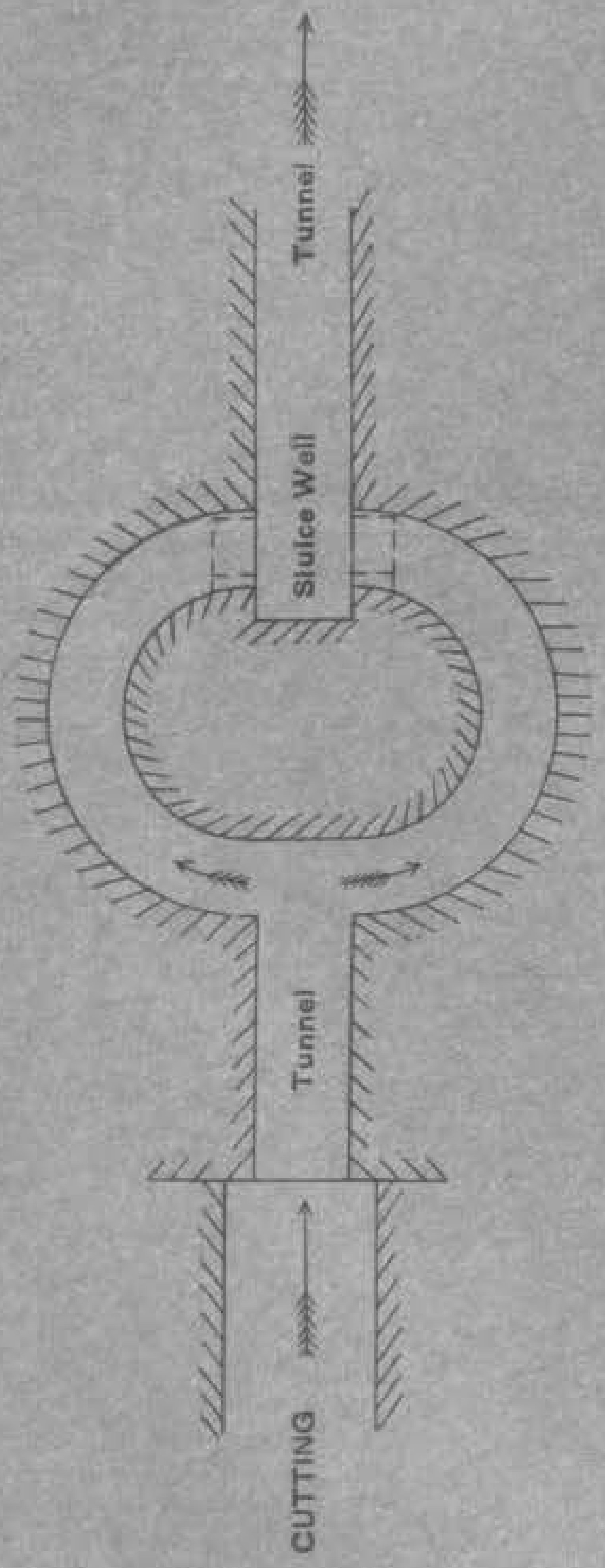
The rock was in places seamed with small fissures, which admitted a little water, but the quantity decreased always after running for a short time. The total quantity of water was never serious, and for a considerable proportion of its length the tunnel was quite dry.

The discharge of the tunnel is a difficult thing to calculate, since with the steep gradient and rough sides there must be a loss by eddies and skin friction which can only be dimly pictured. When the head at the entrance is great an additional effect of turbulence must be produced. It is probable that the maximum discharge is obtained when the tunnel is not quite full, since there is then a surface fall independent of friction against the roof. The estimated discharge was 1,600 cubic feet a second, but it appears that this is somewhat over the mark. A measuring weir, with a sluice in it, has been built across the open outfall cutting, which has the result of submerging the mouth of the tunnel and possibly compresses air inside. Many observations at the weir have been made, but it is only a degree more capable of gauging than the tunnel itself by reason of its conduct being visible. The approach to it not being straight the water is higher at one end than the other, and it is so near the tunnel mouth and the cutting is so narrow that the depth on the crest and the velocity of approach are almost impossible to determine exactly. The following table has however been compiled according to the depth of water on the gauge at the weir and it is at present accepted as the discharge from the lake :—

Depth on weir. FEET.	Discharge. C. FT. A SEC.	Remarks.
0·00	0	To this must be added a quantity varying from 531 cubic feet a second to 0, according as the sluice in the weir is full open or partly open or closed. With no water on crest and vent full open the discharge is 392 cubic feet a second. If water is below crest of weir, the discharge varies between: (1) at 0·25 feet below crest 55 to 382 cubic feet a second, (2) 4·00 feet below crest 38 to 226 cubic feet a second, according as the sluice is full open or partly open or closed.
0·25	26	
0·50	73	
0·75	133	
1·00	207	
1·25	288	
1·50	371	
1·75	472	
2·00	576	
2·25	683	
2·50	797	
2·75	915	
3·00	1,041	
3·25	1,167	
3·50	1,301	
3·75	1,437	
4·00	1,576	
4·25	1,720	
4·50	1,866	
4·75	2,015	
5·00	2,166	

PLAN OF UPPER PORTION OF PERIYAR TUNNEL

SKETCH 1



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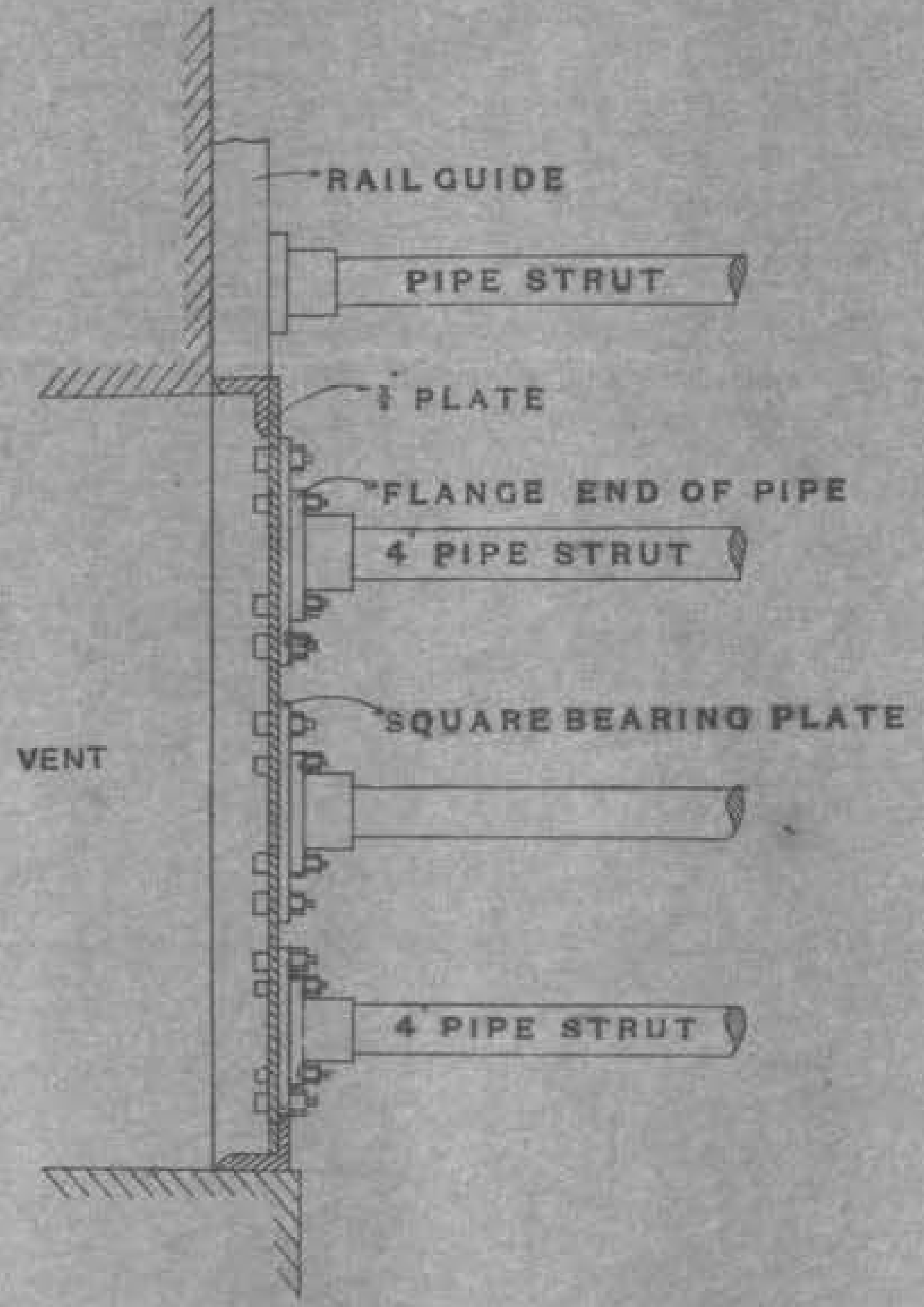

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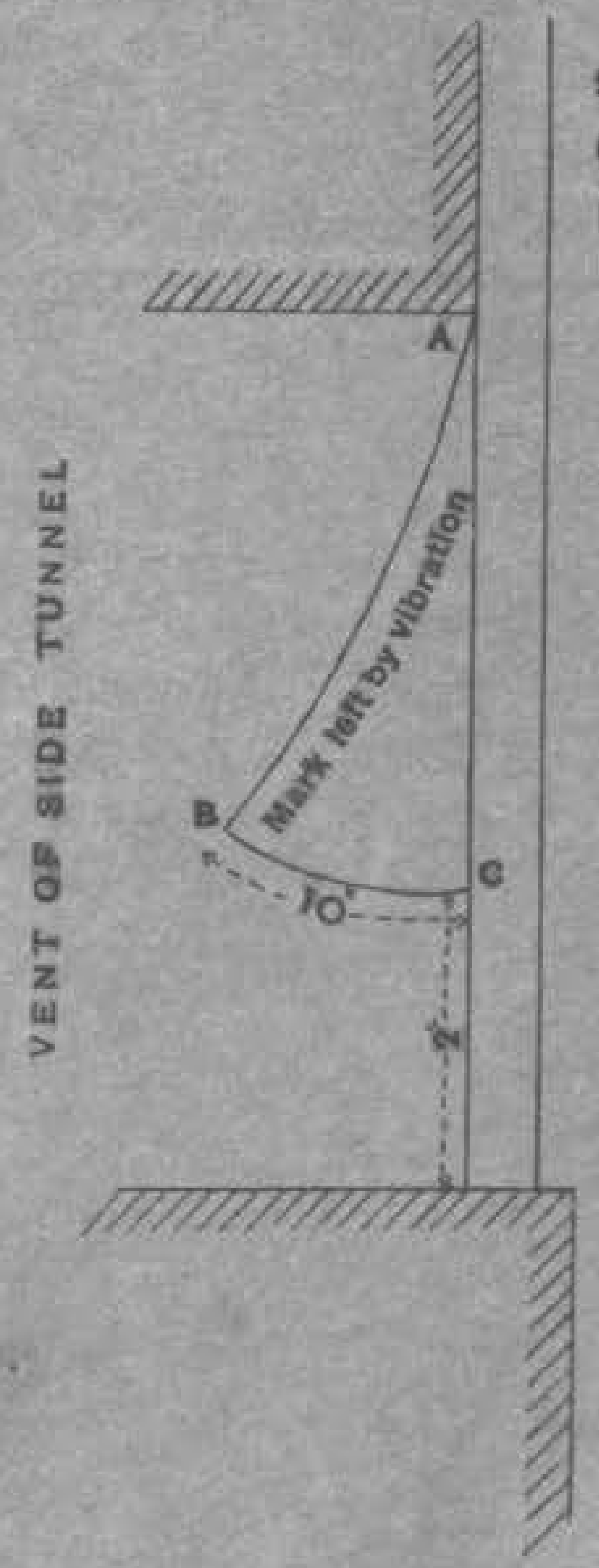

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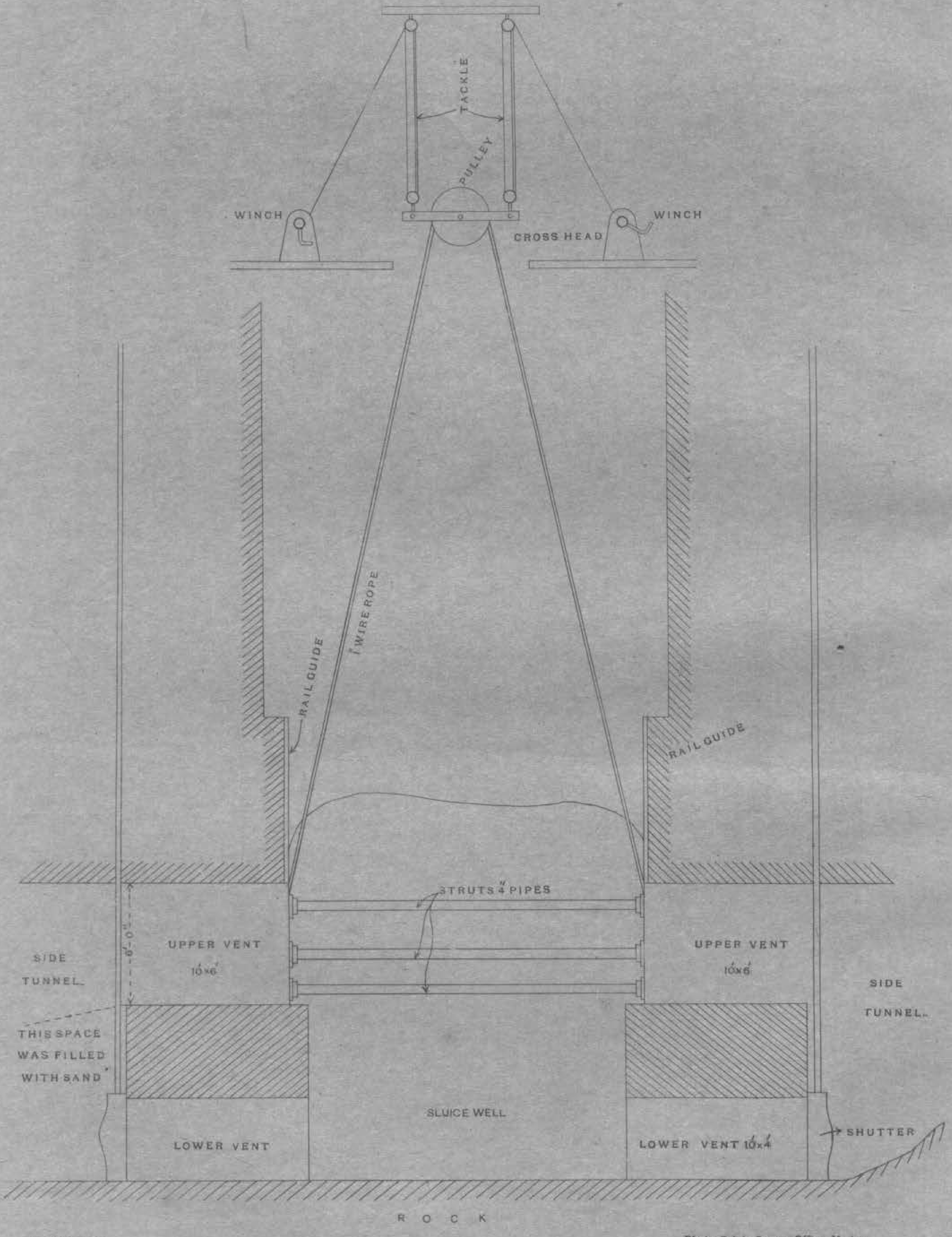
VERTICAL SECTION OF SLUICE WELL

SKETCH 2



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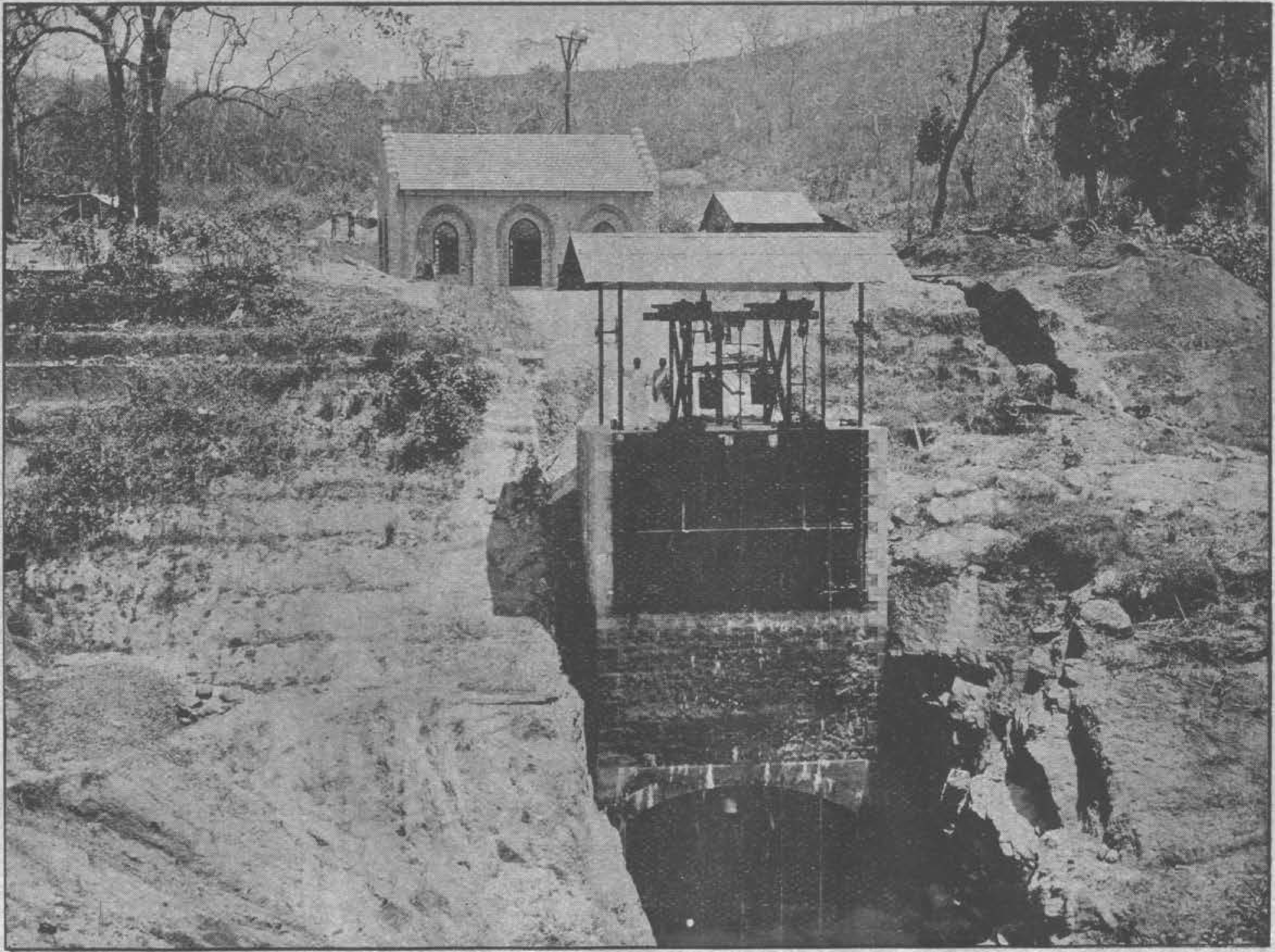

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Survey of India Offices, Calcutta, 1899

ENTRANCE TO TUNNEL.

The sluice-gates at the head of the tunnel, as originally designed, were to have been similar to those in the main dam escape culvert, described on page 24. The design was, however, entirely altered and the gates as actually constructed were according to Plate VI. The tunnel at the head, after a few feet of straight, divides into two semi-circular arms of 15 feet radius, meeting in a chamber from which the tunnel proper continues in a single straight line. At the lower ends of each of the two arms are two vents, one above the other. The upper vents, 10 feet by 6 feet, are for the normal discharge. The lower vents, 10 feet by 4 feet, and arched over, were designed to ensure a continuous discharge of 500 cubic feet a second, in view of the necessity of that amount being supplied permanently for power purposes, and in case repairs or inspection of the gates of the upper vents should be required. The upper or main shutters are connected and worked simultaneously by one gearing. Each shutter is of ⅜-inch plate, and the two shutters are tied together by 15 flanged W.I. 4-inch pipes of $\frac{3}{16}''$ metal, bolted through the shutter plate to bearing plates symmetrically placed. The shutters do not fit close to the vent, the intervening space being closed by angle-irons on the shutters at top and bottom and flanged rails, serving as guides, fixed in concrete at the sides; and the rails are strutted apart by 4-inch pipes. Each gate is suspended by a 1-inch wire rope from a pulley on a cross head in the sluice house. The cross-head is hung from the roof of the house and raised or lowered by tackle from two winches. The arrangement, it will be seen, gives great flexibility.

The lower vents are controlled by shutters, each worked by a screw of 2½ inches diameter passing through a 4-inch pipe passing down a shaft in the rock. They have no guides.

The above arrangements were so unsuccessful that it has not been thought necessary to give further details of them than the accompanying sketch.

It was found in practice that the actual result of suspending the shutter by a rope over a loose pulley was that if one face of the shutter met with an obstruction and stuck the shutter at once got askew and jammed. The violent surging of the water had a similar effect, either end of the shutter swaying up and down alternately. To make the shutter work at all, it was found necessary to wedge the pulley and fix it, and it was difficult and awkward to work the two independent winches together. When the shutter was examined it was found that it had been considerably damaged by the vibration. Several of the lower struts were broken, and most of the others were loosened. The lower shutters were found to get bedded in the sand brought into the tunnel by the water, so as to be almost immovable and the single screw shaft to each shutter was found to be insufficient to prevent jamming.

There was also at the extreme inside end of the tunnel, before the commencement of the two semi-circular arms, an emergency shutter containing within it small pivoted valves designed to pass 500 cubic feet a second when the shutter was down and also to assist in raising and lowering it. This shutter was not however intended for ordinary use.

It was finally decided to abandon these shutters and to substitute for them a Stoney's shutter in the place of the emergency shutter. The design of the Stoney's shutter is given in Plate IX. This shutter has not yet been erected, but the following is an extract from the instructions of the Chief Engineer for Irrigation, Mr. W. Hughes, in requesting a design from Messrs. Ransomes and Rapier :—

"The average section of the tunnel is about 96 square feet and the velocity about 12 feet per second with an average depth in the reservoir and the shutter full open. The present opening at the head of the tunnel was made of its present dimensions merely to afford room for a large sluice gate with valves, but with the arrangement now proposed there is no object in having the opening much larger than the tunnel, and it will therefore be reduced to 12 feet by 10½ feet to soffit of arch).

"It would be inconvenient to have the supports of the counterweights at any considerable height above the platform. It is therefore suggested that the counterweights should be designed to work in a trough in the masonry.

"In a high flood there will probably be heavy rain also on the Madura side of the hills and the tunnel will have to be fully closed. The maximum pressure on the sluice gate will, therefore, be that due to a head on sill of 155·00—106·50 or 48·50 feet. The maximum velocity through the sluice will occur when the lake is high and it is desired to pass only a little water through the tunnel. In this case there will be but slight pressure in rear of the gate and the maximum velocity may be taken as that due to a head of 45 feet. An iron sill will be necessary on this account and to prevent leakage as far as possible.

"A great part of the site of the lake was occupied by forest, and, as the trees and bamboos fall, a great quantity of drift of all kinds is constantly being carried towards the tunnel. A grating to prevent any of this above a certain size reaching the sluice is required and the grating and sluice gate must be designed together. The lift of the shutter will be 8½ feet and the height of the grating at the tunnel end must be at least 12 feet. From experience gained at the Bhátgarh dam it is found most undesirable to have the grating close to a sluice opening.

"It has been found in some sluices that the submerged iron work gets pitted and the friction consequently increased. For this reason it seems advisable that such portion of the submerged metal work as is liable to wear, such as the rollers and surfaces of the roller-paths, should be of non-corrodible metal.

"With regard to the mechanism for actuating the shutter it may be stated that time is of practically no importance, and that it would be quite satisfactory if the mechanism is arranged so that the sluice can be raised or lowered an inch a minute by one man pulling about 20 lbs. to 30 lbs."

Messrs. Ransomes and Rapier submitted a design with the following description :—

"The mechanism consists of the following parts :—Beginning on the up-stream side, there is built into a groove provided in the masonry, a cast-iron frame work or orifice, consisting of a sill girder, a lintel girder, and two jamb pieces. These castings are all bolted together at machined faces, so that true and rigid work is secured; the inside edges are also planed, where the bottom and sides and top of the gate come in contact with them, thus securing a close and satisfactory fit.

"The side castings extend sideways into the wall and are securely built into place; to them are united by means of short lengths of steel joists, the roller path castings. The joists are 3 feet 8 inches long and placed about every 2 feet, so that the whole forms one rigid structure. The roller path casting has a projecting edge or ridge down its whole length. On this rests the actual roller path. This is of cast iron, and truly machined on its face and also in the groove, which fits on the ridge.

"The width of the roller face is 14 inches, this being necessary, owing to the great pressure to which the sluice may be subjected.

"The roller path is free to 'rock' slightly on the ridge, so as to ensure the pressure of the rollers coming equally on the whole width of the roller path.

"The main roller path casting, which is built into the wall, carries a strong steel shield plate to protect the rollers and path against the rush of water when the gate is lifted. This shield plate is easily removable for purposes of inspection.

"The gate is directly supported against the water pressure by 20 pairs of cast-iron rollers. The skin of the gate is of exceptional strength, being ¾-inch thick steel plate.

"The clear opening of the gate is 12 feet 9 inches high by 9 feet 6 inches wide, equal to 118¼ square feet; against 96 square feet, the average sectional area of the tunnel.

"The form of the gate is narrower and higher than that of the tunnel, but this proportion of height to width is much more economical for heavy pressure sluices, as the greater height gives more length of roller path, and the width of the rollers, &c., can then be proportionately reduced.

"The skin of the gate is supported by 14 steel joists, 14 inches by 6 inches, which transmit the load to end castings which rest on the rollers.

"The gate is operated by a screw-lifting gear, and is also balanced to the extent of ⅔ its total weight.

"The balance weight consists of a steel tank filled with stone, and carried by two steel wire ropes, with a factor of safety of 10.

"The lifting screw is of steel and 3½ inches outside diameter, with a double thread, the whole 14 feet being turned in one length.

"On the head of the screw is keyed a massive bevel wheel which is worked by the winch, the ratio of gearing being 27 turns of the handle to one turn of the screw. This will give great ease of working and security against possible break-down.

"The screw is carried throughout in brass bearings; and works in a brass nut of ample length and provided with an oil chamber.

"The nut is bolted to the head of the cast-iron ram, which transmits the motion to the gate. The gearing is, therefore, capable of either lifting or pushing.

"The ram is turned true and passes through a brass bearing at the lower end of the shield tube, so that the screw is protected from weather and dust.

"The sluice chamber is formed by the existing masonry at the back, and on the other three sides by new masonry. The internal dimensions of the chamber are 10 feet 6 inches deep by 15 feet 6 inches wide. On the up-stream side a groove is provided for a temporary door; the sides of the culvert converge at an angle of 1 in 4, so as to get the best efficiency from a given side of sluice and to so direct the stream that it does not strike the rollers, &c., but first touches the shield plate.

"The thickness of the front wall is about the minimum, unless it be built as a regular arch, to take horizontal pressure. The coping stones round the top of the sluice chamber will be rebated about 1½ inches by ½ inch, so as to form a landing for steel foot-plates.

"The screen is formed of 1¼-inch diameter bars, rivetted into frames of convenient width for handling. These are carried on cross joists, set in recesses of the side masonry."

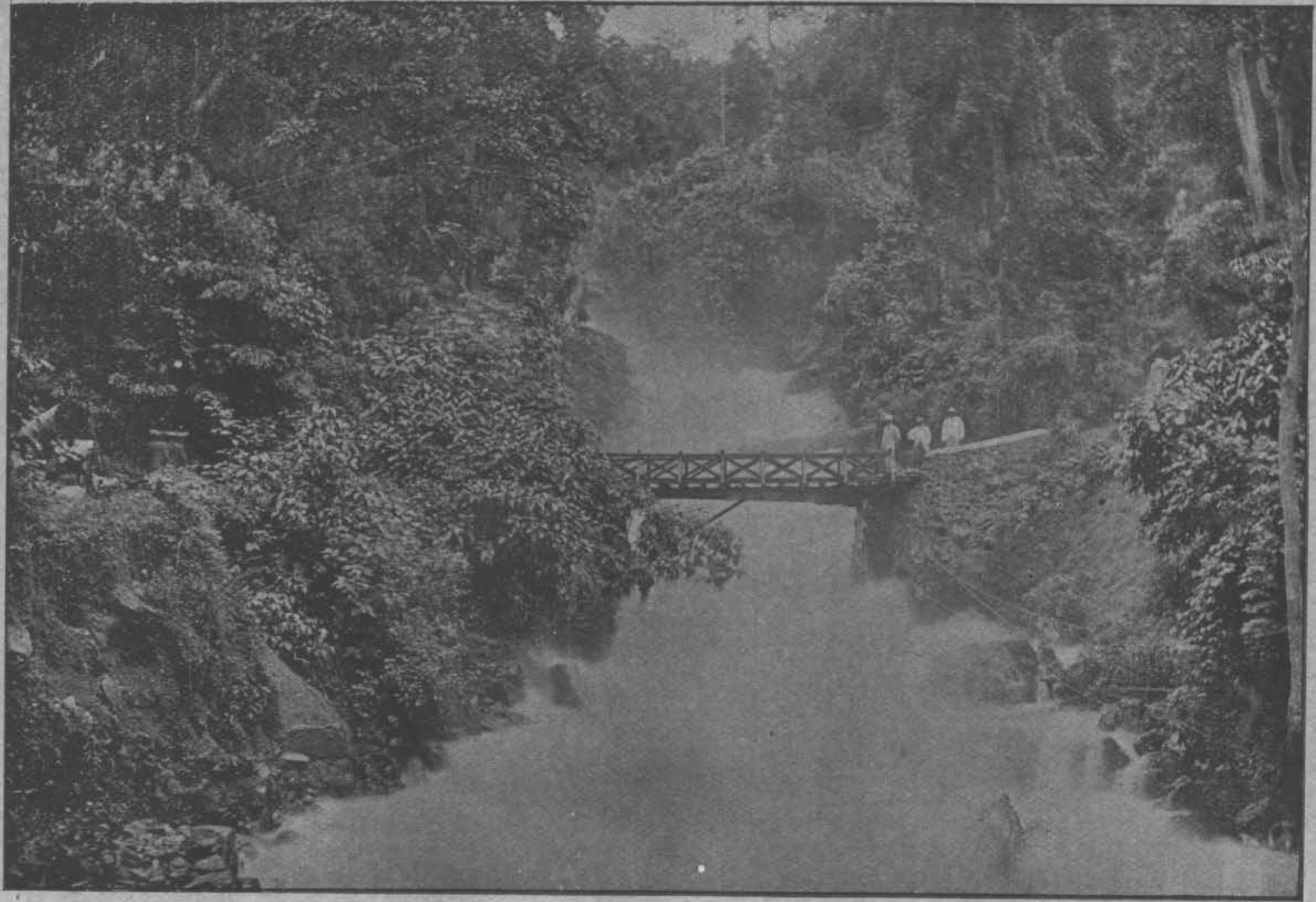

Photo.-Block.

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THE WATER AFTER LEAVING THE TUNNEL.

As regards the use of non-corrodible metal, Messrs. Ransomes and Rapier were of opinion, from actual experience in bad water, that iron was quite safe and much cheaper, and that the introduction of brass set up a galvanic action which rapidly ate away the iron frame work. The sluice was therefore designed by them in steel and iron alone.

Cost of Head Works.

At an early stage of the works it became evident that the estimate for the Head works would be considerably exceeded, on account of the difficulties of the initial operations; but it was hoped that, these once overcome and labour organised, an approximation to the original rates might ultimately be arrived at. As time wore on this hope disappeared, but it was not until 1892 that the obstacles, for which there was neither precedent nor possible forecast, were safely passed, uniform progress attained, and an accurate measure of the ultimate cost rendered possible. In 1893, revised estimates were submitted, of which the following is a summary of the principal items:—

	Original. RS.	Revised. RS.
Main dam and escape culvert with turbine supply culvert	9,59,000	24,60,000
Temporary dams	15,000	29,115
Right bank escape	1,55,000	2,70,000
Left bank extension	46,000	79,885
Water-shed cutting	1,37,000	2,47,000
Water-shed tunnel	2,95,000	4,94,000
Buildings	1,57,000	3,50,000
Maintenance	50,000	97,000
Tools and plant	60,000	7,57,000
Unforeseen works	..	60,000
Miscellaneous	56,000	1,80,000

These excesses caused a corresponding increase in the item of establishment, calculated at 23½ per cent. upon the actual cost of works, though the real charge was very far below this figure. In the early stages of the work there was a painful deficiency of officers and subordinates, a mistake the avoidance of which would have saved enormous sums of money.

To escape recapitulation the subject of the cost of each work is taken in one piece, since the same items appear in greater or less proportion in many of the heads of estimate. Thus the item of petty supervision was largely exceeded throughout, owing to the protracted duration of the works, eight years instead of five, and there was also a large loss, distributed over all the works, upon rice imported by Government and sold below cost price when the price in the plains was high. The following extract from the Chief Engineer's note in submitting the revised estimates treats, in sufficient detail, such other causes as were common to all the component parts:—

"Among these causes, the principal is the insufficiency of the rates allowed in the original estimates. It must be frankly admitted that these rates were much too low; it was expected that the whole work would be done by daily labour with gangs of men carefully drilled and watched, and that machinery would be used to a much larger extent than has been found practicable. These expectations were not realised; it was found impossible with the staff available (and it is doubtful whether it would have been possible with any reasonable amount of establishment) to train and drill the labour in the way proposed, and it became necessary to fall back upon the ordinary methods of 'piece-work.' Time being all-important the piece-workers have been practically masters of the situation and we have had to pay rates enormously in excess of what would have been necessary, if the work could have been done in a more leisurely fashion and if the supply of labour had been unlimited.

"The rates actually paid appear, and are, high, but it must be borne in mind that only a very insignificant fraction of the labour came from a distance of less than 60 miles and most of it from distances greatly exceeding this amount, that each man worked on an average for certainly not more than eight months in the year, and that the enforced idleness caused by the stoppage of work during each hot weather and the loss of time involved in the journeys to and from the labourers' homes had in some form or other to be paid for.

"Another cause which has certainly tended towards a general increase of prices is the political condition under which the works have been carried out. This is a subject on which I wish to say as little as possible, because my views are not in accordance with those of the Government of Madras, but it is impossible to avoid all allusion to it. When the estimates were prepared it was assumed, as a matter of course, that the site of the works and the ground in their neighbourhood would be declared British Territory either permanently or for so long as the works were in course of construction. This was not done, and without going into details of this portion of the history of the works, it may be said in general terms that, for the first four years of their progress, there was absolutely no machinery for maintaining order or for the protection of life and property in the camps, except such irregular and extra-legal machinery as was created by the officers in charge; at a later period a limited criminal jurisdiction was ceded by the Government of Travancore, but the concession was so narrowed and limited that it was almost worthless, and even at the present time the conditions of life in the project camps are by no means such as should prevail among a community of some six thousand British subjects. What the financial effect of this state of things has been, it is of course, impossible to say with any approach to accuracy; but it is certain that any cause which renders a work attractive tends to reduce prices and any cause which renders it unattractive tends to increase them.

"A third somewhat important cause of excess has been the enormous cost of transport of materials, especially of lime, of which some 80,000 tons have been or will be required. This cause has affected all the works more or less, though its principal effect has been on the main dam. The wire ropeway for conveying limestone from the foot of the ghaut to Tékadi camp has been most successful and economical when at work, but the difficulties in erection were very much greater than was expected; it was not until 1891 that it was got to work at all, and since then its working has been by no means uniform or constant, partly owing to the frequent repairs that have been found necessary and partly owing to the uncertainty of the water supply of the stream which provides the power for driving it. By the time the work is completed it will probably be found that at least half of the total quantity of lime used has been brought up by ordinary carts at a cost of about ten times that of carriage by ropeway.

"The cost of carriage from Tékadi to the site of the dam has also been greatly in excess of what was expected; I have never ceased to regret that I did not adhere to my first idea of a light railway, worked by locomotives, for this portion of the journey. It would have saved its cost over and over again and have been both cheaper and more trustworthy than the combined road and water carriage which has actually been adopted.

"The deficiency of water power above alluded to had a special deleterious effect on the tunnel, since the turbine and compressors at the north end, which were by far the cheapest mode of tunnelling, had to stop for want of water for several months in each working season. Progress was consequently slow and a shaft was sunk, a steam-plant purchased and tunnelling proceeded with at two more faces; which made a great difference in cost.

"In the original rates the price of machinery was included for each subhead, and a small sum of Rs. 60,000 only was allowed for tools and plant; but in the course of execution it was found that the machinery was so inextricably applied to several subheads of different works that it was impossible to debit it equitably to each. A separate subhead, tools and plant, was therefore opened to which the sum of Rs. 7,57,000 was debited."

It will readily be seen that the incidence of the above causes of excess cannot be divided proportionately between the various component parts of the work, and it is therefore useless to enter into too minute a disquisition in comparison of the rates as estimated and as executed, the more so as the mode of operation was in several cases altered *in toto*. The following table will however give some idea of the principal differences, bearing in mind that the cost of machinery is excluded from the actual rates:—

TABLE OF RATES.

Periyár No. 1 *Division.*

—	Estimate.	Actual.
	RS. A. RS. A.	RS. A. RS. A.
Maistry, per month	50 0	25 0 to 100 0
Stone-cutter, per day	......	1 0 to 1 8
Mason, per day	......	0 12 to 1 4
Carpenter	......	1 0 to 1 8
Sawyer, per day	......	0 12
Fitter ,,	......	1 4 to 2 4
Driver, per month	......	30 0 to 175 0
Smith, per day	1 4	0 12 to 1 8
Head coolie, per day	0 10	0 8 to 0 12
Coolie, man ,,	0 8	0 6 to 0 8
Do. woman ,,	0 4	0 4
Do. boy ,,	0 3	0 3
Bullocks (pair) ,,	......	1 8
Rubble, quarried and stacked, solid measurement, per 1,000 cubic feet.	75 0 to 80 0	85 0 to 121 0

thickness of earth and decayed rock, the removal of which would have added greatly to the cost of quarrying.

In the original rate of Rs. 15 per 100 cubic feet for concrete no account was taken of labour in mixing and ramming since it was intended that this should be done by machinery. These processes were abandoned as unsatisfactory in comparison with hand labour, and the actual cost of carriage from the tips, mixing, and ramming, was from Rs. 6 to Rs. 6½ per 100 cubic feet. There were also many minor charges, the exact incidence of each of which cannot be worked out, but it may be said generally that there was a considerable under-estimation of the difficulties in commencing operations, in guarding against floods, in procuring sand, in transporting limestone, pending the completion of the wire ropeway and canal, in the amount of work that must be done a second and a third time, in the quantity of Portland Cement required, in timber and carpenters' work for bridges, gangways, ladders, rammers, and shoes for workmen. Labour-saving machinery, in several cases of a type unusual in India, was largely employed and it is not to be wondered at that the amount and quality of the labour used in conjunction, the cost of erection and maintenance, the amount of outturn and the life of the machines, were largely under-estimated. Machinery was nevertheless, on the whole, much cheaper than hand labour would have been, even had it been possible to collect a sufficient force of the latter, which would in itself have been a very difficult operation.

The excesses in the other estimates are mostly due to the general causes already touched on, or to unavoidable under-estimation of quantities. Thus the machinery at the north end of the tunnel took out 5 running feet per day instead of 7, and stopped often for want of water, so that an auxiliary steam plant had to be installed. The quantity of rock in the right bank escape was greater than was expected. In the left bank extension special difficulties, described previously, accounted for a great part of the excess; and the length of the time occupied accounts for a large share in the excess under the heads 'maintenance' and 'miscellaneous'; while the cost of buildings was enormously increased by the extra amount of hand labour found necessary, by the constant fires which often burnt whole lines of huts in a few minutes, and by the necessity of destruction and rebuilding by reason of epidemics. It is improbable that a similar work will ever be undertaken, but should it be so the following general criticisms may be worthy of attention, viz., that all the preliminary works should be in such a state of forwardness that there shall be no doubt as to their capability, before the main works are begun; and that machines should be purchased of double, or treble, or even quadruple the makers' estimate of capacity. It is, however, beyond human possibility that in so extraordinary an undertaking any estimate should, except by chance, approximate to the actual results.

General Remarks.

Before finally quitting the Head works some allusion must be made to various matters which could not be previously treated without hindering the progress of the narrative, but which are yet of historical interest and had a perceptible bearing on the construction of the works. Not the least of these is the subject of health and sanitation, a serious question in all large enterprises, and one which has a considerable influence on the economy of engineering operations, since loss of health and unfavourable environment are drawbacks which can almost be estimated in currency, and the difference between the rates of wages in Nos. I and II divisions is a very fair measure of the disabilities involved in the works which have been described.

The Periyár, as has been generally stated elsewhere, is one of those beautiful spots so common in the tropics where fever lurks behind a smiling countenance. The moderate height above the sea, the vast tracts of virgin forest, the strong sun and heavy rainfall, all constitute favourable conditions for an active and stubborn malaria which was one of the greatest hindrances to the work. From July to February the climate, though never healthy, is much better than in the hot weather months, when fever was so virulent as to compel an annual stoppage of operations. As the water rose in the lake, circumstances were not, at any rate for the time being, improved, since the large area of vegetation submerged and rotted added to the disease. The coolies, ill-fed, ill-clothed and reckless as all coolies are, were rendered more liable to sickness by a cold and dampness to which they were unaccustomed, and constitutions enfeebled by malaria offered little resistance to the assaults of rheumatism, dysentery and pulmonary complaints. From 1887 to 1891 the hospitals were less perfectly organised than afterwards, the changes in the medical staff were frequent and the calibre unequal, and the labourers were slow to convince of the benefits of Western methods of treatment. The hospital returns for this period are, therefore, valueless as a presentment of the health of the various camps. From 1891 onwards they may be taken as more reliable and are given below :—

Month.	Periyár camp.					Tékadi camp.					Remarks.
	Average population.	Total patients.	Patients per 1,000, per month.	Total deaths.	Deaths per 1,000 per month.	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	
1892.											
January	...	...	...	...	...	...	...	...	...	...	Patients who did not attend hospital for more than five consecutive days were considered new patients on re-appearance.
February ...	2,102	452	215	5	2	600	266	443	...	...	
March	1,536	532	346	5	3	750	336	448	3	4	
April	...	...	...	...	...	...	...	...	...	...	Not recorded in progress report.
May	...	...	...	...	...	...	...	...	...	...	
June	...	...	...	...	...	...	...	...	...	...	
July	1,554	361	232	5	3	750	278	371	1	1	
August	1,642	370	225	17	10	1,000	349	349	4	4	
September ...	2,970	336	135	7	3	1,080	332	307	...	...	
October	2,914	326	112	9	3	1,061	429	405	3	3	
November ...	3,739	446	119	7	2	827	429	519	2	2	
December ...	4,440	425	96	21	5	1,350	489	362	4	3	

Month.	Periyár camp.					Tókadi camp.					Remarks.
	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	
1893.											
January	4,044	351	87	28	7	1,325	292	220	10	7	
February ...	...	...	...	...	...	...	...	...	...	...	Not recorded, but remarks in progress report that health bad and growing worse, principally fever and dysentery.
March	...	...	...	...	...	...	...	...	...	...	
April	...	...	...	...	...	...	...	...	...	...	
May	...	...	...	...	...	...	...	...	...	...	
June	1,493	...	...	...	9	1,100	...	...	...	3	
July	2,092	919	439	12	6	1,000	460	460	4	4	
August	2,688	1,038	386	15	6	953	372	390	3	3	
September ...	3,315	1,167	352	14	4	1,003	592	590	1	1	
October	3,975	1,441	363	12	3	1,205	736	611	1	1	
November ...	4,109	1,487	362	9	2	912	638	700	1	1	
December ...	3,815	1,722	451	8	2	908	616	678	3	3	

Month.	Periyár camp.					Tékadi camp.					Remarks.
	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	
1894.											
January	3,710	1,516	409	7	2	825	505	612	1	1	
February ...	...	...	...	48	...	...	...	...	...	...	An outbreak of cholera.
March	...	...	...	37	...	...	...	...	...	...	Population so fluctuating that returns imperfect.
April	...	...	...	...	...	...	...	...	...	...	Sanitary and medical arrangements diverted from other diseases.
May	...	...	...	...	...	...	...	...	...	...	Practically no population.
June	...	...	...	...	...	...	...	...	...	...	
July	2,307	1,312	569	3	1	...	...	...	...	...	From this month Tékadi camp was abolished.
August	3,319	1,492	450	11	3	...	...	...	...	...	
September ...	3,644	1,380	379	5	1	...	...	...	...	...	
October	3,886	1,592	410	13	3	...	...	...	...	...	
November ...	3,904	1,523	390	7	2	...	...	...	...	...	
December ...	3,798	1,271	335	14	4	...	...	...	...	...	

Month.	Periyár camp.					Tékadi camp.					Remarks.
	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	Average population.	Total patients.	Patients per 1,000 per month.	Total deaths.	Deaths per 1,000 per month.	
1895.											
January	3,471	1,111	320	12	3	...	...	...	...	...	
February	3,748	870	232	18	5	...	...	...	...	...	
March	4,008	1,089	271	14	3	...	...	...	...	...	
April	1,449	611	422	9	6	...	...	...	...	...	
May	925	635	686	4	4	...	...	...	...	...	
June	747	1,094	1,465	5	7	...	...	...	...	...	
July	2,418	1,568	648	19	8	...	...	...	...	...	
August	3,266	1,357	415	17	5	...	...	...	...	...	
September	3,596	1,363	379	7	2	...	...	...	...	...	
October	3,206	1,427	445	10	3	...	...	...	...	...	
November	2,551	1,848	724	8	3	...	...	...	...	...	
December	...	...	...	...	...	...	...	...	...	...	

But it must be borne in mind that the fatalism which characterises the lower classes in India and their reluctance to undergo treatment prevent even these returns from being an accurate measure of the hygienic conditions. As an illustration, a return of the deaths in the Periyár camp for January 1896 is given below, taken at random but more nearly typical than might be believed :—

Date.	Name.	Own or father's occupation.	Age.	Cause of death.	Remarks.
1896.			YRS.		
2nd January ...	Sodalimadi ...	Cooly ...	40	Fever ...	Not treated in hospital.
3rd ,, ...	Muniappan ...	,, ...	3	,, ...	
6th ,, ...	Angammah ...	,, ...	1	Fever and ague.	
7th ,, ...	Ramalingam.	,, ...	6	Anæmia.	Treated in hospital.
10th ,, ...	Malayandi ...	,, ...	40	Fever ...	Not treated in hospital.
12th ,, ...	Subramaniam.	,, ...	38	Pneumonia.	Treated in hospital.
16th ,, ...	Sodalimathu.	,, ...	10	Anæmia.	
18th ,, ...	Infant ...	Head cooly.	½	Fever ...	Not treated in hospital.
20th ,, ...	Do. ...	Cooly ...	¼	General debility.	
22nd ,, ...	Pattivan ...	,, ...	34	Ague ...	
25th ,, ...	Muniyandi ...	Mason ...	38	Cirrhosis of liver.	Treated in hospital.
28th ,, ...	Siranandi Tevan.	Cooly ...	38	Leprosy.	Not treated in hospital.

Of these poor creatures, twelve in number, whose names are here given such immortality as can be conferred by an official publication, no less than eight never attended the hospital. All deaths in the camp were ascertained and recorded, but many of the very sick were removed to the plains by their relations to die or recover, and never appear in the returns, and many were sick in their lines and recovered, and the medical officer knew nothing of it. Paying due regard to these facts, a glance at the monthly returns will give an idea of the extent to which disease, mostly fever or consequent complaints, played havoc with the labourers. The number actually treated per thousand per month was at Periyár nearly always more than 300 during the latter part of the work. It was often more than 400 per thousand, sometimes 500, 600 and 700, and during one month (June 1895) was no less than 1,465 per thousand. At Tékadi the health was consistently worse than at Periyár, and it may be seen how at both places the returns of sick steadily increased year by year. Though this increase was partly due to superior hospital organisation and was a tribute to the merits of an exceptionally able Assistant Surgeon, yet a great part was undoubtedly the result of the environment, but whether the cause was the lake or the works, or was an index of unusual seasons throughout the neighbourhood, cannot be decided. The officers and subordinates naturally suffered less than the work-people, being better clothed, housed and fed, but there was not one who did not suffer more or less from fever, and many had to be transferred at different times on that account. This was particularly the case with those who lived at Tékadi and on the Mulia Panján.

Fever is believed to arise largely from the quality of the drinking water used, and in this particular the Periyár was ill-situated and did not admit of measurable improvement. The officers depended chiefly on a small spring which usually ran dry in January, and after that on wells. The subordinates, clerks and maistries drew their water from wells, as also did the hospital. The coolies, both at Periyár and Tékadi, had wells, but mostly resorted to the Periyár or Mulia Panján for drinking water. From this water fever could not be eliminated, but precautions were taken as far as possible to prevent them drinking such as had been used for washing clothes or persons, though their utter recklessness prevented these precautions from being more than partially successful. The water from various sources was analysed and the analysis is given below, but it, of course, conveys no idea of the fever-bearing qualities which were of primary import :—

—	Sub-Magistrate's well.	Hospital well.	Lake.	River.	No. 2 camp well.	Clerks' well.
Total solids, germs per litre.	0·080	0·050	0·060	0·070	0·080	0·090
Volatile solids, germs per litre.	0·040	0·030	0·030	0·040	0·040	0·040
Chlorine, germs per litre ...	0·007	0·008	0·005	0·005	0·007	0·008
Total hardness, Clark's scale.	1°050	0°700	0°525	0°350	0°350	1°750
Permanent hardness, Clark's scale.	1°050	0°350	0°525	0°350	0°350	1°400
Free ammonia, mlgrms. per litre.	0·208	0·104	Trace.	Trace.	0·232	Trace.
Albuminoid ammonia, mlgrms. per litre.	0·320	0·416	0·120	0·128	0·288	0·152
Nitric acid, mlgrms. per litre.	0·900	Trace.	Trace.	Trace.	Trace.	Trace.
Apparent quality inferred.	Doubtful.	Doubtful.	Usable.	Usable.	Doubtful.	Usable.

No smell was observed by the analyst in the specimens submitted to him, though both the lake and the river generally smelt abominably, and the analysis actually shows the lake and river water to be chemically the best. In point of fact fever could not be materially reduced without a complete installation of distilled water, which the coolies would have refused to drink and which was otherwise financially impossible.

There were, however, possible palliatives in warmth and good food. The latter rested with the coolies themselves and although their wages were unusually good, they lived as they always live, most of their extra pay going in cheap jewellery, tinsel and Manchester goods, of which considerable quantities were imported and quickly disposed of. They were enabled to obtain a little more meat than usual, and this was doubtless of value, but the total effect cannot have been very significant. They were undoubtedly eager for meat and the death of an occasional bison or sambur furnished them with an opportunity to festoon the camp with strings of flesh which were left to dry in the sun and were probably most unwholesome. Rice was bought by the Government and retailed at cost price or less, in order to bridle the exorbitance of local vendors, and beyond this nothing could be done. Warmth depended mostly on hutting and firewood. Firewood was easy of access and to be had for the picking, and in this particular the coolies were better off than on the plains in spite of the damper and colder climate. The hutting was throughout a vexed question, and it was only as a choice of evils that the camps were constructed almost entirely of thatch, which was plentiful and convenient. The lines constantly caught fire and probably no huts in the camp had a life of more than three years, the expense of reconstruction therefore being a formidable item; and if mud lines had been built from the beginning the cost would hardly have been greater in the end, and the coolies would no doubt have been better housed. There were however other considerations. A settlement of some 4,000 or 5,000 persons consisting almost entirely of coolies, in a narrow space, connotes an amount of filth beyond the capacity of any reasonable sanitary staff to deal with. Sweepers were difficult to procure and demanded high wages, and a very great deal of money was expended on latrines and general cleanliness, nor were any pains spared to attain a decent hygienic standard. The following was found to be the least establishment capable of maintaining even a superficial cleanliness in a camp of from 3,000 to 4,500 souls:—

			RS.
	A sub-overseer paid from establishment		600
	A sanitary inspector on	Rs. 30	360
Hospital.	A compounder	,, 30	360
	A compounder	,, 25	300
	A midwife	,, 30	360
	A surgery coolie	,, 9	108
	A ward coolie	,, 9	108
	A cook	,, 10	120
	Two sweepers	,, 9	216
	A waterman	,, 9	108
	Five lascars	,, 9	540
	Twenty-six sweepers	,, 9	2,808
	Repairs, various		350
	Sundries		290
		Total per annum	6,628

The sanitary supervision remained in the hands of the Superintendent of Works and was most closely conducted. Nevertheless the soil in and around the lines speedily became clogged and sodden with impurities. Bad as the fever was there was a worse enemy, namely, cholera, of which there were many sporadic cases and two serious epidemics, which not only killed a considerable number of people, but drove the coolies to their villages and caused a dislocation of the work and a strain of anxiety to the staff which it was imperative should not be of frequent occurrence. The following extract from a letter from the Superintendent of Works to the Chief Engineer, dated 11th March 1894, conveys a commentary on one of these epidemics:—

"I have the honour to report that labour has now fallen in consequence of the cholera to such a point that it is impossible to carry on work any longer.

"In an average population of 2,417(5,000 at the commencement and a few scores at the end) there occurred in 20 days 81 cases, of which 45 had ended fatally, not taking into account the deaths which have still to occur amongst the patients still under treatment. This is equivalent to 787 cases and 437 deaths per day in Madras town, with a population of 450,000. Even these figures are far from representing the real severity of the outbreak, for it is known that many of the coolies were attacked after leaving the camp. Five dead bodies have been reported to me as being found on the roads, one died at Kumili, and there must have been many more cases and probably several deaths.

"For the first nine days of the epidemic the infected houses were burnt down and their sites disinfected, every hut in the camp was fumigated, medicines were distributed, orders were given to boil all drinking-water, drains and latrines were disinfected with quicklime and strenuous exertions were made by cleanliness and any other measures that suggested themselves to stamp out the disease. As these all proved ineffective, it was determined to transport the whole population into a temporary rest camp on the south bank of the river. This was done and immediately resulted in a short lull in the number of cases. The disease soon reasserted itself however, and after a week it was decided to allow the coolies to return to their former camp which had meanwhile been thoroughly sprinkled with solution of corrosive sublimate and afterwards with quicklime. Another lull followed which again proved delusive. There remained nothing to be done except to patrol the lines, with a view to taking each case in good time, and to isolate and disinfect, by burning, in each case as it occurred. The population continued to dwindle and one line after another to disappear by firing, till there now remain about 200 coolies, the exodus not yet ended, and the camp is merely a patch of blackened ground."

The Sanitary Commissioner added as a corollary to this report that the camp had been too long occupied, irrespective of cholera, and should be moved, on account of the general contamination of the soil with organic matter.

The constant fires in the lines were therefore not an unmixed catastrophe, since they were more efficient purifiers than any number of sweepers. They would not have occurred, or not so thoroughly or so frequently, in mud lines, and such lines could not have been abandoned and rebuilt elsewhere and the sites broken up and left to purify, as was often done with the grass lines. After the cholera epidemic of February 1894 the whole camp was burnt and transferred to the other bank of the river, with manifest benefit when cholera again occurred in the ensuing season, and, failing to find a *nidus* or channels of transmission, was easily segregated and stamped out.

A brief reference must be made to the subject of accidents, from which no great work can be altogether free. The majority were connected with nitro-glycerine or detonators and were nearly all due to the incredible carelessness of the labourers. A prolific cause of accident was misfires in the blasting. A misfire was always marked with a red flag and pointed out to the drillers, who, however, frequently removed the flag and used a jumper in the drill-hole, in order to give it the appearance of a new hole and receive payment for it. The result was generally not long in doubt, but it was remarkable how often injury alone, and not death, occurred in consequence, and how many recovered from wounds seemingly fatal. One man, fishing with stolen dynamite, blew off both his arms and one eye, blew a hole from below his chin into his mouth, received severe flesh wounds on his chest and face, and lay bleeding for 6 or 7 hours; and yet made a good recovery. There were also naturally a certain number of accidents from machinery, but wonderfully few resulted in death. One such accident will however always retain a mournful prominence, an accident by which on 12th October 1891 Mr. H. S. Taylor, then Superintendent of Works, lost his life in the prime of his strength and in the midst of a career that promised great distinction. Mr. Taylor was in executive charge of the works from their commencement in 1887, and, in the words of His Excellency the Governor in Council in recording his sorrow at the event and his sense of the loss which the public service sustained thereby, "the success with which the difficulties attending this important undertaking have been grappled with is in no small degree due to his energy and professional skill."

CHAPTER III.

Amount of water available—Description of distribution works.

In designing the distribution works the first requisite was an estimate, as reliable as was possible, of the quantity of water available for irrigation. With this view rainfall observations were taken at a point not far from the subsequent site of the main dam during the years 1869–1873, and the discharges of the river were gauged during the same years. The tables VI and VII in the appendix give in tabular form the results then arrived at. Similar observations at two stations were afterwards made during the years 1889–96. The average rainfall during these years, at the observing stations, was somewhat less than the average of table VI, while the average discharges were somewhat more. The river discharges according to depths on the gauge below the main dam were calculated from sections and from velocities partly observed and partly computed, and were as follows:—

Depth on gauge.	Discharge.	Depth on gauge.	Discharge.
FEET.	C. FT. A SEC.	FEET.	C. FT. A SEC.
1	0	13	17,075
2	490	14	19,809
3	636	15	22,733
4	1,433	16	25,682
5	2,180	17	29,003
6	3,907	18	32,556
7	5,575	19	35,638
8	7,352	20	39,432
9	8,796	21	42,373
10	10,728	22	46,251
11	12,755	23	50,509
12	14,975	24	53,811

The monthly average depths on the gauge from 1889 were as follows:—

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Remarks.
1889	...	...	...	3·03	2·90	3·38	5·16	4·90	6·76	5·70	4·29	4·17	
1890	2·91	2·20	2·23	2·37	1·85	2·58	3·81	3·90	3·19	4·47	3·97	3·39	
1891	3·05	3·08	3·38	2·99	2·90	3·82	5·05	4·05	3·42	5·61	6·27	4·91	
1892	4·06	3·53	3·11	3·52	3·20	2·60	5·40	5·17	4·12	4·24	3·88	3·30	
1893	3·53	3·54	4·32	3·80	X	X	X	4·38	4·17	4·85	5·10	3·58	X gauge washed away.
1894	3·36	3·19	3·23	3·15	3·18	3·77	4·93	4·36	4·74	4·32	5·20	4·57	
1895	3·66	3·19	3·40	...	...	...	...	...	...	...	...	...	After March the river was entirely diverted.
Average depth ... Ft.	3·43	3·12	3·28	3·14	2·81	3·23	4·87	4·46	4·40	4·86	4·78	3·99	
Average discharge C. ft. a sec.	980	700	860	750	610	840	2,080	1,780	1,730	2,080	2,070	1,430	
Total average discharge ...	41,942 millions of cubic feet per year.												

For reasons stated in describing the tunnel it is not easy to check the above figures by the actual discharge during the season 1896-97 (the only season for which there are records at present) but it can be roughly done. Taking the full discharge of the tunnel at 1,100 cubic feet a second, the amount delivered during 1896-97 was about 24,000 millions of cubic feet, and there was about 16,000 millions of cubic feet of surplus discharged over the escape. Adding 2,000 millions of cubic feet for evaporation on the Periyár lake and 1,000 millions for addition to the contents, the total amounts to 43,000 millions of cubic feet, from which it would appear that the discharges in the above table agree fairly with the estimate. The season 1896-97 chanced to be one of rather heavy rainfall, but in any case in designing the distribution works the estimated delivery into the lake was taken at 32,900 millions of cubic feet, from which was deducted 1,740 millions for evaporation on the lake, 990 millions for evaporation in the Suruliár and the Vaigai, and 500 millions for preliminary absorption in the beds of these rivers, leaving 29,670 millions available for irrigation: and this quantity was considered to be easily capable of irrigating 90,000 acres of first crop and 60,000 acres of second crop.

The Periyár water, after leaving the tunnel, enters the bed of the Vairavanár, and then the Suruliyár, the latter a tributary of the Vaigai, by which it flows to Peranai (an existing anicut on the Vaigai about 20 miles west of Madura), at which point the distributary channels take off. From the tunnel to the junction of the Suruliyár and the Vaigai is about 46 miles and from thence to Peranai about 40 miles.

There are two anicuts on the Vairavanár and thirteen on the Suruliyár, from which 12,000 acres have hitherto been irrigated, the supply being ample, except in very dry seasons, for the requirements of these crops; and the conformation of the country precludes the idea of any important extension of irrigation in this quarter. It is probable that about 80 cubic feet a second of Periyár water is the utmost that can be abstracted for any possible increase. It was at first proposed to pass the Periyár water round the flanks of these anicuts in such a manner that it could be shut off from the channels taking off from them, so that if demands were made for more water, the amount could be measured and the usual charge made. The insignificance of the quantity that could possibly be required rendered the expense of such works disproportionate to the profit, and it was eventually decided merely to repair the anicuts and to provide head sluices to the existing channels. This has accordingly been done, 1 cubic foot a second being allowed for 30 acres direct irrigation and 8 acres tank irrigation, and the ryots are to be allowed to take what water they wish for the existing wet cultivation, but no extension of the latter is to be permitted. This arrangement will have an almost inappreciable effect upon the Periyár supply, and as the latter will be almost perennial storage in tanks will be unnecessary and the expense of maintaining the existing tanks will be saved and should be credited to the Periyár project.

The waterway of the Vairavanár and Suruliyár from the foot of the ghaut to the second anicut is too small to carry the whole of the Periyár water and will have to be enlarged and trained. This has not yet been done, nor was it included in the estimates. Below the second anicut the section and bedfall are sufficient. If the Suruliár is dry the Periyár water passes over the anicuts with a depth of from 10 inches to 1½ feet, but when the river itself is in flood the extra depth due to the Periyár water will not amount to more than a few inches. One masonry bridge has been built across the Vairavanár and two across the Suruliyár, and two more will have to be constructed, but although the Periyár water has emphasised the necessity of these bridges they were previously a crying want and the cost of their construction has not been debited to the project. Their absence was a great source of expense and delay to the head works. The lowest contract rate for carriage from the railway to Tékadi, a distance of 76 miles, was one rupee a hundredweight for small articles, but in the case of large packages special arrangements had to be made for trollies, elephants, lifting and breakdown tackle, and large gangs of coolies, and instances occurred in which machinery was as long as six months on the road, and one expensive coil of steel wire rope was quite spoilt by long immersion in the bed of a river.

The distribution works, as originally proposed and as revised, are best given in tabular form :—

	Originals. RS.	Revised. RS.
Main Canals.		
Preliminary expenses	18,000	24,708
Land compensation	1,14,535	74,184

	Originals. RS.	Revised. RS.
I.—Reach.		
Repairs to Peranai anicut	5,000	..
Head sluice	71,700	27,353
Regulators	20,800	..
Scouring sluice	..	16,108
Head sluice to Vadagarai channel ..	..	5,284
Fall and bridge	6,200	6,625
2 bridges	15,700	..
4 bridges	..	26,138
5 cross drainage culverts	32,500	28,260
2 aqueducts	7,800	10,299
Surplus sluice to Ramarajapuram ..	34,000	34,543
Do. to Nachikulam ..	16,100	..
Iron trough	..	1,000
7 irrigation sluices	..	3,936
Earthwork	1,40,655	1,50,758
II.—Reach.		
Regulator	..	11,000
3 inlets and outlets	34,790	..
2 aqueducts	..	37,359
Culvert	6,500	5,070
Cross drainages	..	3,440
Trunk road diversion	6,620	..
Bridge	5,700	5,903
Sluice	..	1,190
Earthwork	34,680	53,541
III.—Reach.		
7 inlets and outlets	97,780	..
6 superpassages	..	85,660
1 aqueduct	..	21,852
Culvert	..	222
Drop	..	2,075
3 bridges	10,500	10,632
3 sluices	5,310	..
4 sluices	..	5,496
Earthwork	71,665	1,03,228
IV.—Reach.		
Inlet and outlet	12,380	..
Culvert	..	6,767

	Originals. RS.	Revised. RS.
IV.—Reach—cont.		
2 weirs	..	750
Sluice	1,770	1,388
2 iron troughs	..	1,983
Bridge	..	3,100
Earthwork	8,395	24,992
V.—Reach.		
3 aqueducts	93,340	..
2 superpassages	..	43,826
2 culverts	..	9,837
2 iron troughs	..	1,710
2 bridges	7,650	7,361
Earthwork	29,035	30,300
VI.—Reach.		
2 inverted syphons	12,300	..
1 inlet and 2 outlets	20,660	..
1 weir	..	3,929
2 syphon culverts	..	9,265
1 superpassage	..	8,890
1 culvert	..	2,889
2 iron troughs	..	1,793
1 bridge	3,460	..
3 bridges	..	8,094
Earthwork	35,375	49,300
VII.—Reach.		
3 inlets and outlets	37,140	..
3 culverts	..	10,540
1 superpassage	..	10,192
1 bridge	1,040	..
2 bridges	..	6,994
Diversion of road	1,100	..
Earthwork	22,405	22,405
VIII.—Reach.		
Inlet and outlet	12,380	..
2 outlet weirs	..	2,440
Diversion of nullah	..	1,000
Bridge	3,670	..
Bridge and regulator	..	8,150
Earthwork	9,475	14,500

	Originals. RS.	Revised. RS.
IX.—Reach.		
2 inlets and outlets	24,760	..
2 culverts	..	12,639
Sluice	1,770	650
Earthwork	5,660	10,099
X.—Reach.		
2 inlets and outlets	24,760	..
2 culverts	..	9,176
Sluice	1,770	650
Bridge	..	2,000
Earthwork	3,660	4,200
XI.—Reach.		
5 drops	15,990	..
1 drop	..	1,150
4 inlets and 9 outlets	91,320	..
5 outlet weirs	..	6,310
4 culverts	..	11,090
2 superpassages	..	7,850
Sluice	1,770	650
3 iron troughs	..	3,000
Bridge	2,380	..
5 bridges	..	11,060
Earthwork	30,650	39,512
XII.—Reach.		
2 inlets and outlets	24,760	..
1 outlet weir	..	1,000
1 drop	..	1,000
Bridge	2,380	..
Earthwork	4,260	6,000
Buildings	10,000	27,352
Maintenance during construction	53,000	53,034
Distributaries.		
Preliminary expenses	10,000	9,496
Land compensation	69,285	69,285

	Originals. RS.	Revised. RS.
I.—Branch.		
2 head sluices	3,540	2,050
8 drops	5,820	..
7 drops and sluices combined	..	6,166
2 culverts	5,480	..
Superpassage	..	1,220
Culvert	..	1,000
Aqueduct	..	1,400
Road tunnel	..	400
11 sluices	3,150	..
Earthwork	13,530	6,038
II.—Branch.		
Head sluice	1,770	2,260
3 drops	1,950	..
2 drops and sluices combined	..	2,005
1 drop	..	640
Culvert	2,740	..
3 culverts	..	952
Road tunnel	960	..
2 road tunnels	..	645
4 sluices	1,270	..
Earthwork	5,500	4,435
III.—Branch.		
2 head sluices	2,250	..
1 head sluice	..	1,624
12 drops	8,700	..
7 drops	..	5,910
4 drops and sluices combined	..	3,899
Culvert	2,740	..
Superpassage	..	1,003
Road tunnel	..	615
14 sluices	4,150	..
12 sluices	..	3,490
Earthwork	9,240	8,335
IV.—Branch.		
2 head sluices	4,270	3,295
5 regulators	2,400	..
2 regulators	..	691
21 drops	18,730	..
11 drops	..	8,432

	Originals. RS.	Revised. RS.
IV.—Branch—cont.		
11 drops and sluices combined ..	..	8,509
2 drops and road tunnels combined ..	..	3,875
2 drops and weirs combined ..	..	2,026
3 road tunnels	2,370	..
4 road tunnels	..	1,635
1 slab drain	..	281
26 sluices	8,380	..
36 sluices	..	11,050
Earthwork	37,750	37,750
V.—Branch.		
Head sluice	1,770	1,071
Regulator	480	480
16 drops	10,470	..
14 drops	..	8,292
2 drops and sluices combined ..	..	1,149
2 iron aqueducts	1,500	..
8 sluices	2,590	..
10 sluices	..	3,250
Bridge	790	330
Earthwork	10,665	10,565
VI.—Branch.		
Head sluice	1,770	1,100
9 drops	5,740	..
8 drops	..	4,070
Drop and sluice combined	..	580
Slab drain	..	280
6 sluices	1,930	1,930
Earthwork	6,745	6,745
VII.—Branch.		
Head sluice	1,770	1,100
8 drops	4,590	4,590
4 sluices	1,280	1,280
Earthwork	1,460	1,460
VIII.—Branch.		
Head sluice	1,770	1,100
2 regulators	960	960

	Originals. RS.	Revised. RS.
VIII.—Branch—cont.		
12 drops	7,750	7,750
5 sluices	1,930	1,930
Earthwork	7,090	7,090
IX.—Branch.		
2 head sluices	4,270	..
1 head sluice	..	2,440
5 regulators	2,400	1,920
44 drops	38,930	..
2 drops and regulators combined ..	..	1,130
40 drops	..	33,340
Drop and superpassage combined ..	..	1,750
4 drops and sluices combined ..	..	2,460
6 culverts	16,440	..
4 culverts	..	3,230
2 superpassages	..	2,900
3 road tunnels	3,500	2,010
44 sluices	14,870	..
40 sluices	..	13,440
Earthwork	56,640	56,640
X.—Branch.		
3 head sluices	5,110	4,420
3 regulators	1,440	1,440
29 drops	36,260	..
22 drops	..	22,400
5 drops and sluices combined ..	..	5,190
19 culverts	52,060	52,060
Road tunnel	1,270	1,270
33 sluices	11,560	11,560
Earthwork	66,225	66,225
XI.—Branch.		
Head sluice	1,770	1,050
Regulator	480	480
6 drops	4,680	..
10 drops	..	7,680
Road tunnel	960	960
12 sluices	3,810	3,810
Earthwork	13,150	13,150

XII.—Branch.

	Originals. Rs.	Revised. Rs.
Head sluice	2,500	2,500
3 regulators	1,440	1,440
Drop	2,040	..
5 drops	..	5,240
3 road tunnels	3,020	3,020
30 sluices	54,220	54,220
Earthwork	9,930	9,930
Buildings	5,000	5,000
Maintenance during construction ..	40,000	40,000
Unforeseen works	..	4,844
Total main canal (12 reaches) ..	13,67,000	12,64,000
Total distributaries (12 branches) ..	7,53,000	7,15,000
Grand total ..	21,20,000	19,79,000

Subsequent to the submission of the revised estimates it was determined also to excavate minor distributaries except such as irrigated less than 50 acres, and these will amount to a further sum of about Rs. 2,00,000.

From the above statement it will be at once seen that the distribution works were both numerous and important, and such as to demand great skill and judgment in design. In the course of the work the whole of the canals were re-aligned and every masonry work designed afresh, so that it is unnecessary to deal with the works except as thus modified.

Peranai anicut and head sluice.

As above stated, the point selected for off-take from the river Vaigai was at Peranai, an old anicut of native construction, for the benefit of the Vadagarai channel, which already irrigated 4,200 acres through an open head. This anicut is 1,300 feet long and runs in a tortuous line skew to the river (see Plate XIII). The crest is not uniform, there being in places a difference of a foot in level, and the section also is very irregular. Through repeated repairs, however, it has become fairly massive and though the maximum flood velocity is computed to be 28 feet per second the greater part of the coping is of granite, and it was therefore decided not to make extensive alterations. For 900 feet on the right the foundation is of rock and the coping is laid on a body wall of brickwork of varying depth. The left portion is built on soft soil, and a massive but irregular apron has accumulated in rear. These portions were left practically untouched, but on the extreme left a scouring sluice was built consisting of 5 vents of 5½ feet by 6 feet (see Plate XV). The shutters are worked by screw gearing from a platform 10½ feet above the crest of the anicut and 3¾ feet above the highest recorded flood, the sill of the sluices being 7½ feet below the crest. On the right and left massive wings form a junction with the anicut and head sluice, respectively, and the left bank of the river in rear is heavily revetted.

The head sluice is an important structure of 8 vents of 10 feet span, with sluice gates 10¾ feet by 9 feet worked by double screws connected by a chain on toothed pinions. The sills are 6 feet below the anicut crest, the platform being at the same level as that of the scouring sluice. The area of the vents when free from silt is 480 square feet and they are designed to pass 2,016 cubic feet a second with a velocity of 4·20 feet. The dimensions and particulars will be best seen by a reference to the plan (Plate XIV).

Main canal.

The main canal is nearly 38 miles in length and is divided into eleven reaches, the particulars of which are as follows :—

Number of reach.	Length.			Bottom width.	Side slopes.	Depth.	Bedfall per mile.	Velocity per second.	Discharge per second.
	M.	F.	FT.	FT.	FT.		FT.		CUB. FT.
1	7	2	0	100	1½ to 1	6	1·16	2·81	1,838
2	3	2	0	71			1·19	2·74	1,315
3	6	3	190	68·8			1·20	2·74	1,279
4	1	2	140	62·0			1·21	2·70	1,150
5	2	2	90	51·2			1·24	2·64	954
6	3	6	400	48·5			1·25	2·65	914
7	1	6	560	46·8			1·25	2·66	890
8	1	2	200	46·2			1·25	2·66	881
9	1	1	460	43·7			1·27	2·62	828
10	0	6	640	27·3			1·37	2·63	573
11	5	4	0	15			1·59	2·70	389

From the main canal diverge twelve branches composed as follows:—

Number of branch.	Length.			Bottom width.	Side slopes.	Depth.	Bedfall per mile.	Velocity per second.	Discharge per second.
	M.	F.	FT.	FT.		FT.	FT.	FT.	CUB. FT.
1	*	...		12	1½ to 1	6	6	2·17	65
2	1	3	540	4		6	6	1·76	26
3	4	0	450	7·75		6	6	1·94	42
4	4	7	160	19·5		6	6	2·30	104
5	5	0	500	5		6	6	1·84	30
6	3	3	100	3		6	6	1·65	20
7	*	...		0·75		6	6	1·33	10
8	3	0	360	4		6	6	1·71	24
9	10	0	568	30		3	3	2·57	265
10	7	2	520	27·5		3	3	2·58	248
11	5	2	380	9		3	3	2·33	94
12	18	1	550	22		4	3	2·97	333

* Not yet dug.

The country in the vicinity of the Vaigai is undulating and irregular, and by no means ideal for irrigation, necessitating much deep cutting and rock excavation, many sharp curves, and numerous drops and regulators. There is also a great deal of cross drainage and existing irrigation which it was inconvenient to command from the Periyár channels, and a large number of masonry works was requisite on these accounts. A further large item is the bridges of various sizes, amounting to no less than 45 on the main canal and main branches, which have had to be provided wherever a cart-track, however exiguous, previously existed, and which have debited the project with a considerable capital charge, while extra expense has also been incurred by adapting many of the drops, regulators and superpassages to the same purpose. An economical alignment was rendered difficult by a period of scarce rainfall which occurred just before the course of the main canal was laid out. Work had to be found at once for a large number of coolies at various points, and these points thus became fixed for the future, and the rest of the line had to be worked in to meet them. Apart from this convenience of command was the first consideration, followed by facility in cutting cross drainages, and after allowing for these factors, the rest of the line was then laid out in the most economical manner possible. It was, on the whole, found best to cut through ridges instead of following contours, a reduction of nearly two miles in length being thus effected with a corresponding saving in head and in maintenance, modified by a slight increase in distributaries. The total length of the main canal is nearly 38 miles, the depth being throughout 6 feet, and the carrying capacity 2,016 cubic feet a second at the head, and 288 cubic feet a second at the tail, where it runs into the 12th branch. The side slopes are 1½ to 1 in earth, vertical in rock, there is a berm of 10 feet on each side, and the designed height of the banks is 12 feet above the bed with slopes of 2 to 1 and a top width of 6 feet. The bottom width is 100 feet at head and 12 feet at tail, the surface fall varying from 1·16 to 2·53 feet per mile, giving a velocity of from 3 to 4 feet per second. The total fall is 71·19 feet, which includes four drops aggregating 19·25 feet, the afflux at superpassages and the level lengths in the beds of fourteen tanks passed through. The bank is double throughout to exclude cross drainage, except for three flush inlets where the canal is commanded by Mattaparai tank, and near large cross drainage works the upper bank is made 1 foot or 1½ feet higher than normal. Where the cutting was greater than the economic routine section, all extra spoil was thrown on the right bank to assist in widening the inspection road, except where the left bank needed strengthening against floods, but where roads for traffic had to be made or diverted parallel to the canal they were made at the outer toe of the banks. Trees are being by degrees planted along the toe to afford shade and mark the boundary. In places where the soil was loose, grass was dibbled on the banks, in some places they were turfed, and in a few it was necessary to plant sea-pink. All approaches to cross-drainage works were revetted, as well as three of the tanks passed through, namely, Rámarajápúram, Náchikúlam and Vedakúlam. In cases where extra earthwork for the banks was needed, borrow pits were at first made in the bed of the canal, leaving a 10-feet berm, but excavation in the deep soil was costly, and it was therefore found advisable to take earth from outside the banks, leaving 15 to 18 feet of margin. The work thus done was in some cases directly advantageous, since it lowered the level of fields which would not otherwise have been commanded. The banks were found to stand best which were formed of soil the result of disintegrated surface rock, as they became quickly

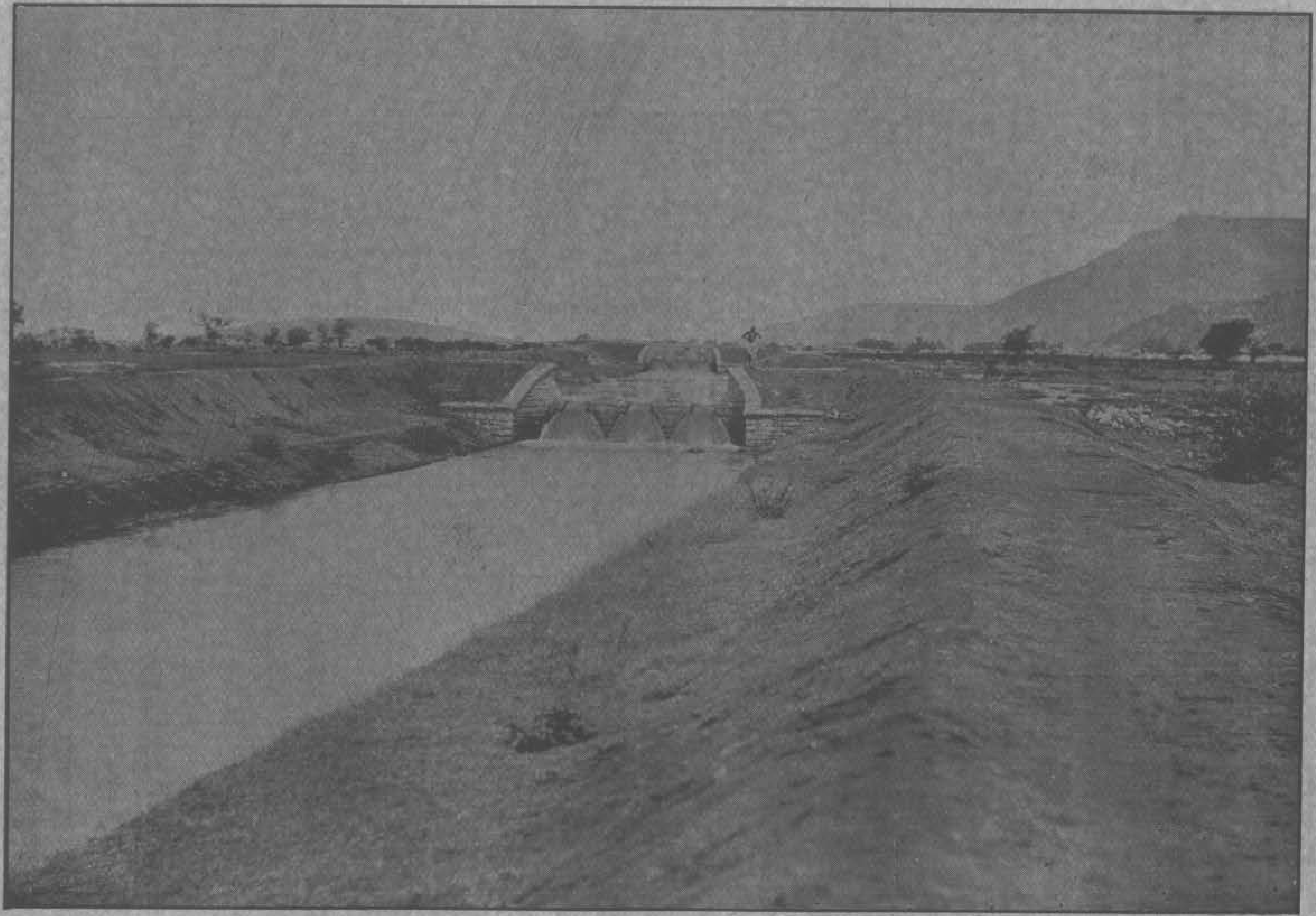

Photo-Block. Survey of India Offices, Calcutta, 1899.

FALL ON THE MAIN CANAL.

covered with natural grass. The most troublesome banks were those formed of yellow soil mixed with kunkur, or of black cotton soil. High banks of the latter material have spread at the base and have had to be helped in places with revetment. In delicate places the berms were sloped inwards and the top of banks outwards and small turf banks constructed to direct the drainage. The 1st, 3rd, 6th, 11th, 18th, 21st and 26th miles were in deep cutting in rock or hard red soil with bands of kunkur. Elsewhere the soil was easy to excavate.

Cross drainage.

The slope of the country is naturally steep, being as much as 1 in 150 over wide areas, and there are numerous bare hills, while the whole drainage basin is singularly devoid of trees and small vegetation, with rock often exposed or but a short distance below the surface. Falls of rain of 1 inch in 15 minutes and 5⅜ inches in 12 hours have been observed, and on these grounds a high percentage of run off was allowed for, the actual figures being as follows:—

Area, SQ. MILES.	Run off per hour. INCHES.
0·5	1·20
1·0	0·93
2·0	0·74
3·0	0·65
5·0	0·54
10·0	0·43
18·0	0·35
20·0	0·34
25·0	0·31
75·0	0·22

The areas were taken from village maps of 8 inches to the mile and the discharges of the various nullahs were not calculated from sections or bedfalls, which were extremely variable. All cross drainage with but one important exception was designed to be passed either under or over, not through the canal, and there are no flush inlets or outlets of any significance. The result has been a great saving in initial cost of masonry works, and it has been unnecessary to consider the effect of heavy rainfall and full supply in the canal at the same time. There were in all 12 superpassages, 3 aqueducts, 25 culverts, and smaller cross drainage works, amounting in all to 55 including weirs of tanks, in the length of the main canal. The crossings of the nullahs were, as previously stated, fixed so as to ensure good foundations and sufficient headway, though small nullahs were occasionally diverted in order to make one masonry work serve for two. The most important of these works were Rámarajápúram surplus sluice in the 4th mile, Andipatti aqueduct in the 11th mile, and Shattiyár and Marangaliyár superpassages in the 19th mile.

Rámarájapúram surplus sluice is situated at 3 miles 7 furlongs, close to the tank of the same name, and is designed for a catchment of 75 square miles with a discharge of 10,688 cubic feet a second. It consists of 12 vents of 10-feet span and has a waterway of 1,200 square feet. The platform is 6¾ feet wide carried on 2 arches, 1½ feet deep and 2¼ feet rise, each 3 feet wide with 9 inches between them for a passage for the lifting gear, which is fixed at 20 feet above the sill. The shutters can thus be raised 10 feet and if they are not open a flush escape of 120 feet remains. The sills of the vents are 4 feet below the bed of the canal, and the shutters are 10 feet deep, so as to hold up a full supply of 6 feet in the canal. The bed of the canal is here pitched, and in rear of the surplus sluice are two cushion floors of cyclopean rubble in mortar. The total length of this work between abutments is 164 feet.

Andipatti aqueduct is at 10 miles 7 furlongs and is designed for a catchment of 14⅓ square miles, and a discharge of 4,300 cubic feet a second through the subterpassage. The length between faces of parapets is 84 feet and between the ends of cushion walls 109 feet. The clear width is 72 feet, comprised in 3 arches of 24 feet span, 4 feet rise, and 2 feet thick at the crown. The intrados is plastered, but the extrados which forms the bed of the canal is unplastered. There is no drop wall, the cistern being cut in rock.

The Marangaliyár superpassage is situated at 18 miles 7 furlongs on the main channel and is designed to pass a jungle stream rising in the Sirumalai hills which rise to 4,000 feet and are sparsely covered with jungle. The catchment area of the stream is 62 square miles. The original design has been found faulty, insufficient waterway having been allowed for the stream, and on the 23rd August 1894 a flood came down spilling over the side walls and also causing a breach 70 feet wide in the left bank of the main channel. The rainfall that caused the breach was, as far as can be ascertained, generally speaking, moderate (unless something approaching a cloud burst occurred in some part of the catchment area), and had been preceded by dry weather. The flood was mainly caused by a tank breaching and carrying several others below it in its course.

The superpassage was originally designed to carry a flood discharge of 6,300 cubic feet a second, calculated as follows:— $D = C\sqrt[3]{m^2}$; $C = 430$; $M =$ the area of the catchment basin in square miles $= 56$. It is not known what was the actual flood discharge on 23rd August, but the discharge now allowed for is calculated on an area of 62 square miles by the above formula with the co-efficient $C = 700$; therefore $D = 10{,}962$ cubic feet a second. It was originally reported that the Shattiar river crossing the main channel by a work similar to this at 18 miles 3 furlongs spilled over its banks into the Marangaliyár which is at a lower level; but this has been denied by all the ryots owning lands between the two streams. The originally calculated M.W.L. is 588·56. The observed flood level is 591·72 and the calculated M.W.L. 593·56. The side walls and wings have accordingly been raised 3 feet.

The superpassage now consists of a single segmental concrete arch 24 feet span with a rise of 4 feet, the thickness at crown being 2½ feet. The side walls of the tunnel are 5 feet high and the floor (R L. 570·56) is sunk to 4 feet below channel bed. The maximum upward pressure on the arch is that due to a head of 10 feet and no spouting has been observed. Over the concrete is a layer of slab stones 6 inches thick. The drop walls in front and rear are semi-circular on plan, 14 feet high, 2 feet wide at top and 5 feet wide at base, battered on the inside. The internal radius at base is 18 feet. The work is built throughout of coursed rubble coped with dressed stone, the side walls of the tunnel only having a base of concrete. The stone is a hard close-grained gneiss obtained by burning sheets of rock common in the district. The lime is got from nodular limestone The heading up of the channel has been inappreciable, as has also been the case in the other superpassages; several culverts have, on the other hand, silted badly and given trouble. Where either can be used superpassages are eminently superior to undertunnels.

The Marangaliyár stream is perennial, and this was the only instance in which steam pumping was required in the foundations.

From reaches 5 to 12, both inclusive, the following dimensions were adopted for all superpassages, which were of the same general design :—

Reach.	Span.	Height to springing.	Rise.	Area.
NO.	FEET.	FEET.	FEET.	SQ. FEET.
5	24	5	4	84
6	24	5	4	184
7	24	4½	4	172
8	24	4½	4	172
9	20	5½	4	163
10	16	5	3	112
11	12	4½	3	70
12	8	5	2	51

Regulators.

There are three regulators in the main canal at 7 miles 5 furlongs, at 27 miles 4 furlongs, and at 32 miles 4 furlongs. The first, which is much the most important, is at Náchikúlam tank and consists of 5 vents of 15 feet span, the arches springing from piers 7 feet above the floor and rising 2½ feet. The shutters are 5 feet high and the maximum supply level is 8½ feet above the bed, and the discharge therefore with shutters down amounts to 1,458 cubic feet a second, which is the maximum discharge in this reach. In case of necessity the waterway above the shutters can be closed with planks. The shutters do not run in grooves but on plane surfaces, as water-tightness is not essential, the only object being to hold water up and by forcing excess water over the weir of Náchikúlam tank to prevent floods from running down the canal. The shutters are 15 feet by 5 feet with double 2-inch screws fixed 3 feet from the end of each shutter. The sliding surfaces are iron joists 7 inches wide and 3¼ inches deep, weighing 20 lb. to the foot run, built into the floor and into the arch ; and the shutters work on iron rollers of 9 inches diameter on 1½-inch axles, placed at 1 foot and 3 feet from the bottom of the shutter.

The second regulator is built at 27 miles 4 furlongs at the end of the Pappankúlam tank and is combined with a bridge giving 15 feet of roadway. The vents are three of 16 feet span, 7 feet deep to springing, with a shutter platform 5 feet wide. The shutters are 16 feet by 5 feet and are worked on the same principle as those of the Náchikúlam regulator.

The third regulator is a small affair of 3 vents of 6-feet span, the piers being 7½ feet to springing. It is built at 32 miles 4 furlongs below Devimangalam tank and is worked with removable planks.

There are four drops or falls in the main canal aggregating 21¼ feet. The width of the canal was reduced from 82, 68·8, 15 and 12 feet, to 32, 30, 10 and 7 feet, respectively, at the drops, in order to maintain the depth in front at full supply level. All are sheer overfalls and the design is simple, needing no further description than a reference to the plan (Plate XVI). Where the drop is combined with a sluice on the upstream side there is inequality in the foundations, both in the main canal, and in the branches in which numerous drops occur, and in the result there have been instances of unequal settlement and parting at the junctions.

The sluices on the main canal are not in any way unusual, the principal being the Vadagarai channel head sluice which consists of 2 vents of 10-feet span, the pier and abutments 5 feet high to springing and the arches 2 feet rise, with ordinary screw-gearing shutters. Below the sluice ten iron standards are set up in the main canal, in which planks can be fixed to turn all water down the Vadagarai channel when there is no Periyár water in the Vaigai. The general type of the sluices on the main canal is an arched vent or vents of small span with screw-gearing shutters, and a platform 4½ feet to 6 feet above F.S.L. The barrels of the vents have 18-inch collars at 10 feet intervals to prevent creeps. From 6 to 9 feet of roadway is allowed between the parapets.

A few general remarks will suffice to close the subject of the construction of these works. The highest floods in the Vaigai will occur in May or November, and full supply will be let into the main canal in June, July, August and September, so it is unlikely that both will occur at the same time. Cross drainage is, however, as previously observed, kept out of the canal, and as a measure of precaution no account of the downward pressure from water in the canal is taken in calculating the efficiency of the arches of the aqueducts in resisting upward pressure. The Vaigai itself between May and September generally carries but from 10 to 150 cubic feet a second, the maximum observed during any year being 33,824 cubic feet a second on 8th November 1884, equivalent to a run off of 0·905 inches in 24 hours, from a catchment of 520 square miles of hills and 870 square miles of plains. The platform of the head sluice has been built 3¾ feet above the maximum level of this flood.

The foundations of the principal masonry works were nearly always on rock, very occasionally on hard clay or kunkur. The spans were usually 24 or 25 feet to economise centerings, but in small or low arches earth centerings were often used. The arches were generally concrete, but for spans of less than 7½ feet slabstones were employed. The bricks in the neighbourhood were bad, therefore the masonry throughout was of coursed rubble or burnt stone in mortar, the rock throughout the country being a species of syenite or gneiss. The faces of the stones were chisel-drafted but rough at the back to bond with concrete in the case of voussoirs for arches. The lime, burnt from kunkur found in the vicinity, was of good quality, and the masonry is very solid and of useful appearance. The mortar was composed of 1 part lime, 1½ sand, ¼ surki, by measurement, and the concrete of 2¼ parts of stone to 1 of mortar in archwork, otherwise of 3 of stone to 1 of mortar. In archwork the concrete was laid circumferentially in 6-inch layers and the top of each course was grouted. In the case of superpassages the floors were covered over the concrete with large 6-inch stone slabs laid diagonally. The centering was generally removed after a month, but sometimes after a half or even a third of that time without ill effects. Concrete was, on the whole, economical as compared with rubble masonry, since the masons of Madura, though of considerable local reputation and undoubtedly clever stone-dressers, devour very nearly half the year in holidays. For this and other reasons large contracts were found inadvisable and nearly all the work was done by piece-work. The principal rates will be found in table II.

CHAPTER IV.

Irrigation—Total expenditure—Returns.

In all large undertakings, such as the Periyár project, the question of construction is but ephemeral. When the dust has cleared away, two much more lasting and important considerations arise—first, whether the work done will be of real utility to the country, apart from any direct returns; and second, whether the revenue arising from the work will represent a reasonable interest on the capital expended. The first question may readily be answered in the affirmative. In the opening chapter of this book, mention was made of the frequent, even constant, scarcity of water in the neighbourhood of Madura, and of the sufferings and expense that resulted therefrom. It is beyond cavil that the mere fact of pouring such a vast quantity of water as is represented by the Periyár river down the bed of the Vaigai and through the distribution canals must in itself be of inestimable benefit. The wells, the cattle, the crops, the pasture, the fish, must all feel the effects, which though not measurable in rupees are obvious and incontrovertible. From the standpoint of a just and humane Government, this is after all the most important aspect, and an aspect of particular importance in the Madura district. A large number of useful human beings are *practically secure from want.* The point is most noteworthy, though apt in criticism to be neglected. It need not here be further enlarged on.

In the other question—that of returns—it is twenty years too soon to form an authoritative opinion. All that can be done is to tabulate the forecasts, to narrate the present progress, to describe briefly the obstacles and the encouragements that have so far made themselves manifest.

In the year 1875, after considerable correspondence and previous investigation, the Government of Madras deputed the late Mr. H. F. Clogstoun to submit a complete report on the probable result from a financial point of view of the contemplated works. This report was submitted in a very thorough and exhaustive form in July 1876. Passing over the indirect, but manifest advantages resulting merely from the difference between irrigated and unirrigated land, Mr. Clogstoun divided his enquiry into three branches—

(1) The classification and grain valuation of all Government lands irrigable by the project, and a determination of the probable cost of cultivation of the same lands with rice, in view to arriving at the surplus produce or *profit*, available for division between the Government and the cultivator.

(2) The determination of a commutation rate and an assessment which, while rendering the cultivation of rice so advantageous to the ryots as to ensure that irrigation shall be in great demand, shall yet give to Government a fund sufficient to guarantee a fair profit on any reasonable expenditure in providing this irrigation.

(3) The selection from the whole area commanded of that land to which water may be most advantageously supplied, as also the area on which it may be advisable to permit the growth of second crop in preference to extending the area of single crop cultivation.

The conclusion of the report treated of the probable length of time required to bring under wet cultivation the large area, 150,000 acres, which the channels are capable of irrigating, with a few remarks on the general state of the district and upon any circumstances connected with the customs or habits of the ryots or with the nature and quality of the lands of the district which might tend, prejudicially or otherwise, to affect the success of the project.

Mr. Clogstoun's report was the deciding factor in determining the Government of Madras to press for the prosecution of the work. The classification of soils was, in totals—

	ACRES.
Black clay	65
Do. loam	45,482
Do. sand	1,305
Red loam	20,172
Do. sand	26,896
Total ..	93,920

of which 44,374 acres was wet and 49,546 acres was dry. Of the land already wet 4,357 acres was inam, and of the dry land 3,400 acres.

The grain valuation, the result of numerous experiments and a wide experience, was taken as follows, after a deduction of 20 per cent. for vicissitudes of season and allowance for waste:—

		MEASURES.
Black clay,	1st sort	800
Do.	2nd ,,	720
Do.	3rd ,,	640
Do.	4th ,,	496
Do.	5th ,,	496
Black loam,	1st ,,	800
Do.	2nd ,,	720
Do.	3rd ,,	640
Do.	4th ,,	496
Do.	5th ,,	496
Black sand,	1st ,,	720
Do.	2nd ,,	640
Do.	3rd ,,	560
Do.	4th ,,	496
Do.	5th ,,	496
Red loam,	1st ,,	800
Do.	2nd ,,	720
Do.	3rd ,,	640
Do.	4th ,,	496
Do.	5th ,,	496
Red sand,	1st ,,	720
Do.	2nd ,,	640
Do.	3rd ,,	560
Do.	4th ,,	496
Do.	5th ,,	496

the average of which per acre in an average year amounts to 672 Madras measures, an estimate considerably below the result of actual experiments in the same tract of country and much less than that of other districts under similar conditions.

The commutation rate.

Mr. Clogstoun then proceeded to examine the rate at which the grain valuation should be commuted into a money valuation. He found that the average selling price of paddy in the Madura district from 1844 to 1864 was Rs. 128-8-0 per garce, and from 1854 to 1874 Rs. 181-10-0 per garce, while the average price in the Madura district and the neighbouring Tinnevelly, Trichinopoly and Tanjore districts combined, from 1844 to 1864 was Rs. 123–9–0 per garce, and from 1854 to 1874 was Rs. 169–9–5 per garce. From these prices he deducted 15 per cent. as representing merchants' prices, &c., and the sale price of the ryots became—

	RS.
Madura, 1844 to 1864	107
The four districts	105
Madura, 1854 to 1874	154
The four districts	144

and he therefore adopted a commutation rate of Rs. 120 per garce, which he considered well within the mark. It may be noticed that the commutation rate early in the century was fixed at Rs. 60 per garce, showing a very great and growing increase.

From the above rate a further deduction for cultivation expenses was necessary in order to fix a reasonable water-rate. This deduction Mr. Clogstoun fixed at Rs. 10–8–6 per acre on the average, composed as follows :—

	RS.	A.	P.
Cost of implements	1	0	0
Do. of seed	1	0	0
Do. of manure	1	8	0
Do. of labour	7	0	6
Total ..	10	8	6

The average grain valuation being 672 measures per acre or Rs. 25–3–2, the value of the net outturn per acre, allowing for vicissitudes of season, becomes very nearly Rs. 14, of which it is usual to take half as the Government assessment.

Mr. Clogstoun then entered into an exhaustive consideration of the extra revenue to be expected, dividing the land for this purpose into three groups, according as it was at present irrigated by anicut channels, by korambu channels, or by rain-fed tanks, and deducting, of course, the existing assessment. The conclusions he arrived at were—

	Extent.	Total net value of extra assessment.
	ACRES.	RS.
First group	1,000	15,328
Second group	4,000	25,000
Third group	75,878	4,27,136
Total ..	80,878	4,67,464

to which he added 15,210 acres of dry land in inam and zamindari villages, the water-rate on which would amount to Rs. 91,260, the totals thus becoming—

Expenditure of water equal to the irrigation of single crop	Acs. 96,088
Extra assessment	Rs. 5,58,634

Finally, Mr. Clogstoun then considered the question of second crop, his conclusions on which point are stated below. The general summary of the report was that a return might be looked for of Rs. 4,67,374 from a total area of 93,000 acres, equivalent in its demand for water to an area of 80,878 acres, in Government villages; of Rs. 91,260 from 15,210 acres of inam and zamindari land; and of Rs. 2,15,648 for a second crop from 53,912 acres; making a total return of Rs. 7,74,274 from an area of 150,000 acres of irrigation. Colonel Pennycuick considered that these estimates were moderate except in the one point of second crop, always an uncertain subject upon which to prophesy, and the Director of Revenue Settlement in submitting Mr. Clogstoun's report proposed to reduce the estimated return on this account from Rs. 2,15,648 to Rs. 1,00,000. This, however, Colonel Pennycuick considered an error in the opposite direction, in view of the known anxiety of the ryot to get as much as possible out of his land and the certainty of water being available. He, therefore, estimated the return on this account at Rs. 1,41,374, making a total expected return of Rs. 7,00,000. In this total no account was taken of the sums to be realised by the sale of occupancy rights either of fresh land or of the beds of tanks to be abandoned, or of indirect revenue on account of fresh land taken up in place of existing dry converted into wet, although the project was debited with the assessment of existing cultivation.

The estimates of returns were accepted with some slight modifications and were submitted to the Government of India in the following shape :—

Description of land.	Taram.	Estimated yield per acre.	Irrigable area.	Rate per acre.	Revenue.
	NO.	MAD. MEAS.	ACS.	RS.	RS.
Government	1	1,000	16,431	8½	1,39,663½
Do.	2	900	29,522	7½	2,21,415
Do.	3	800	21,905	6½	1,42,382½
Do.	4	700	5,849	5½	32,169½
Do.	5	620	2,643	5	13,215
Total ..	...	...	76,350	...	5,48,845½
Tank-beds	...	...	9,196	8	73,568
Usual wet inam	...	...	4,856	Free.	...
Dry inam	...	...	9,400	6	20,400
Zamindari	...	...	15,216	6	91,260
Total ...	...	...	108,538	...	7,34,073½
Deduct revenue due to old irrigation, average of ten years' collections.	...	...	...	...	1,52,598
Net total ...	...	...	...	...	5,81,475½
Deduct area and revenue of land not advisable to irrigate under the project	...	...	7,538	...	22,849½
Net total ...	...	...	101,000	...	5,58,626
Second crop ...	...	...	...	...	1,41,374
Total ...	...	...	101,000	...	7,00,000

The extent of unoccupied lands to be brought under irrigation was estimated at 35,998 acres, viz. :—

	ACS.
Dry lands	20,616
Wet ,, ...	6,186
Tank beds	9,196
Total ..	35,998

which should produce Rs. 46,122 as enhanced land revenue at Rs. 1-4-6 per acre, the average rate of dry assessment.

These forecasts were accepted by the Government of India with some modifications, and the figures of gross revenue were submitted to the Secretary of State for India as follows :—

		RS.
From 85,790 acres, Government land	.. .. ..	4,67,374
From 15,210 acres, inam and zamindari lands ..	..	60,840
From second crop irrigation	.. ..	1,00,000
Total gross revenue	..	6,28,214
Maintenance charges at Rs. 1¼ per acre	..	1,25,400
Net revenue	..	5,02,814

The forecast of growth of irrigation and revenue receipts and charges was as follows :—

Revenue Receipts and Charges.

Year.	Irrigated area.	Gross revenue due to works.			Direct and indirect charges on revenue account.	Net revenue due to works.	
		Direct receipts.	Enhanced land revenue.	Total.		Including enhanced land revenue.	Excluding enhanced land revenue.
	ACS.	RS.	RS.	RS.	RS.	RS.	RS.
Seventh ...	11,000	57,580	4,600	62,180	20,040	42,140	37,540
Eighth ...	21,000	1,15,874	9,200	1,25,074	40,080	84,994	75,794
Ninth ...	31,000	1,74,164	13,800	1,87,964	60,120	1,27,844	1,14,044
Tenth ...	41,000	2,32,454	18,400	2,50,854	80,160	1,70,694	1,54,294
Eleventh ...	51,000	2,90,745	23,000	3,13,745	1,00,200	2,13,545	1,90,545
Twelfth ...	61,000	3,49,038	27,600	3,76,638	1,05,440	2,71,398	2,43,798
Thirteenth.	71,000	4,07,330	32,200	4,39,530	1,10,280	3,29,250	2,97,050
Fourteenth.	81,000	4,65,621	36,800	5,02,421	1,15,320	3,87,101	3,50,301
Fifteenth...	91,000	5,23,913	41,400	5,65,313	1,20,360	4,44,953	4,03,553
Sixteenth...	101,000	5,82,214	46,000	6,28,214	1,25,400	5,02,814	4,56,814
Seventeenth	101,000	5,82,214	46,000	6,28,214	1,25,400	5,02,814	4,56,814
Eighteenth.	101,000	5,82,214	46,000	6,28,214	1,25,400	5,02,814	4,56,814

The above figures were compared with the forecasts of expenditure on works, together with the loss by exchange and the price proposed to be paid to the Travancore Government, and an estimate of annual profit was thereby formed. The three items named, however, subsequently underwent great alterations, and it would be useless here to set down the calculations as submitted to the Secretary of State for India with the plans and estimates in 1884, and sanctioned in the same year.

The works, in course of construction, were visited by Sir Charles Elliot, then Public Works Minister, in 1890, when a certain amount of actual experience had been gained, and at his instance further information was compiled and some of the figures reconsidered. It was decided to deal with the different classes of lands to be benefited by the project as shown in the subjoined abstract.

I. Ryotwar occupied lands—

(1) *Dry.*—For first crop a water-rate of Rs. 5 per acre and for second crop Rs. 3. At the next revision of assessment the whole to be placed in first group wet and treated as double crop lands.

(2) *Wet.*—To be charged first group wet assessment. For second crop 50 per cent. of the first crop assessment to be charged pending revision.

II. Ryotwar unoccupied lands including tank-beds—

These lands to be converted into first group wet and charged a consolidated assessment for two crops, with the exception of one-eighth of the area believed to be incapable of supply for second crop.

III. Minor inams—

(1) *Dry.*—To be charged water-rate at Rs. 5 per acre for first crop and Rs. 3 for second crop, and no charge made in revision.

(2) *Wet.*—No additional charge for first crop, but for second crop half the assessment at first group rates.

IV. Whole inams and zamindaries.—No water available for dry lands or first crop on wet lands, but during second crop season Rs. 3 charged on about 8,000 acres.

The financial results, according to these principles, would be as follows:—

Nature of land.	First crop.	Increase.	Second crop.	Increase.	Total.
	ACS.	RS.	ACS.	RS.	RS.
I. Ryotwar occupied—					
(1) Dry	27,440	1,37,201	13,720	41,160	1,78,361
(2) Wet	43,446	93,919	21,723	52,428	1,46,347
II. Ryotwar un-occupied including tank-beds.	33,744	2,15,048	29,526	94,355	3,09,403
III. Minor inams—					
(1) Dry	4,847	24,236	2,424	7,271	31,507
(2) Wet	5,041	...	2,520	5,437	5,437
IV. Whole inam and zamindari.	...	...	8,000	24,000	24,000
Total ...	114,518	4,70,404	77,913	2,24,651	6,95,055

From this it will be seen that the forecast of land under second crop was considerably augmented. It was, at the same time, decided not to sell waste lands by auction, the preferential right of the ryots of a village to the occupation of the waste land within it being admitted; but tank-beds were placed on a different footing and were to be sold by auction, the amount to be realised from this item being estimated at Rs. 6,41,133.

In all the forecasts two elements of doubt necessarily existed, namely, the cost of the works and the acreage that would be irrigated. By 1894 the former had been practically removed and the figures were finally revised as follows:—

Summary of Capital Expenditure.

	RS.
Land compensation	1,43,469
Works—	
Other works	61,82,531
Total	63,26,000
Establishment	14,01,000
Tools and plant	7,57,000
Less receipts on capital account	13,000
Net total	84,71,000

Summary of Indirect Charges on Capital Account.

	RS.
Capitalized abatement of land revenue	82,500
Leave and pension allowances	1,96,500
Total	2,79,000

Summary of growth of Irrigation and Revenue Receipts and Charges.

Year.	Area irrigated at end of each year.		Estimate of revenue receipts and charges.					
	First crop.	Second crop.		Gross revenue.		Working expenses, direct and indirect.	Net revenue due to works.	
	ACS.	ACS.		RS.		RS.	RS.	
1896–97	11,468	7,794		72,179		61,498	10,681	
1897–98	22,918	15,585		1,44,237		82,101	62,136	
1898–99	34,368	23,376		2,16,295		1,02,704	1,13,591	
1899–1900	45,818	31,167		2,88,353		1,23,307	1,65,046	
1900–1	57,268	38,958		3,60,410		1,43,909	2,16,501	
1901–2	68,718	46,749		4,32,468		1,47,512	2,84,956	
1902–3	80,168	54,540		5,04,526		1,51,115	2,53,411	
1903–4	91,618	62,331		5,76,584		1,54,718	4,21,866	
1904–5	103,068	70,122		6,48,642		1,58,321	4,90,321	
1905–6	114,518	77,913		7,20,700		1,61,924	5,58,776	
1906–7	114,518	77,913		7,20,700		1,61,924	5,58,776	
1907–8	114,518	77,913		7,20,700		1,61,924	5,58,776	
1908–9	114,518	77,913		7,20,700		1,61,924	5,58,776	
1909–10	114,518	77,913		7,20,700		1,61,924	5,58,776	
1910–11	114,518	77,913		7,20,700		1,61,924	5,58,776	
1911–12	114,518	77,913		7,20,700		1,61,924	5,58,776	
1912–13	114,518	77,913		7,20,700		1,61,924	5,58,776	
1913–14	114,518	77,913		7,20,700		1,61,924	5,58,776	
1914–15	114,518	77,913		7,20,700		1,61,924	5,58,776	
1915–16	114,518	77,913		7,20,700		1,61,924	5,58,776	

The figures in column 7 include the payment of Rs. 40,000 annually to Travancore, and the collection charges at 5 per cent. on revenue. The working expenses are estimated at 12 annas per acre on ultimate first crop area. The total amounts to 6·38 per cent. on the total amount of estimate, instead of 8·92 per cent. as previously anticipated.

The revised estimate of net financial results was prepared in 1893 before the works were finished, but the difference between the revised estimate and the actuals of expenditure was too slight to materially affect the figures:—

Estimate of Net Financial Results.

Year.	Direct capital outlay.	Interest at 4 per cent.	Net revenue.	Simple interest less revenue.	Net revenue less simple interest.
To end of—	RS.	RS.	RS.	RS.	RS.
1892–93	50,82,141	4,68,665	...	4,68,665	...
1893–94	64,25,658	2,30,156	...	2,30,156	...
1894–95	74,70,658	2,77,926	...	2,77,926	...
1895–96	82,00,658	3,13,426	...	3,13,426	...
1896–97	84,71,000	3,33,433	10,681	3,22,752	...
1897–98	84,71,000	3,38,840	62,136	2,76,704	...
1898–99	84,71,000	3,38,840	1,13,591	2,25,249	...
1899–1900	84,71,000	3,38,840	1,65,046	1,73,794	...
1901–2	84,71,000	3,38,840	2,16,501	1,22,339	...
1902–3	84,71,000	3,38,840	2,84,956	53,884	...
1903–4	84,71,000	3,38,840	3,53,411	...	14,571
1904–5	84,71,000	3,38,840	4,21,866	...	83,026
1905–6	84,71,000	3,38,840	4,90,321	...	1,51,481
1906–7	84,71,000	3,38,840	5,58,776	...	2,19,936
1907–8	84,71,000	3,38,840	5,58,776	...	2,19,936
1908–9	84,71,000	3,38,840	5,58,776	...	2,19,936
1909–10	84,71,000	3,38,840	5,58,776	...	2,19,936
1910–11	84,71,000	3,38,840	5,58,776	...	2,19,936
1911–12	84,71,000	3,38,840	5,58,776	...	2,19,939
1912–13	84,71,000	3,38,840	5,58,776	...	2,19,939
1913–14	84,71,000	3,38,840	5,58,776	...	2,19,936
1914–15	84,71,000	3,38,840	5,58,776	...	2,19,936
1915–16	84,71,000	3,38,840	5,58,776	...	2,19,936
Total ...	...	80,61,566	82,65,045	24,64,895	26,68,374
Deduct ...	...	...	...	...	24,64,895
Net surplus revenue ...	...	...	...	...	2,03,479

It now only remains to narrate briefly the advance of irrigation so far as it has at present proceeded. The area commanded consists of existing first-class irrigation, and of second, third, and fourth,—of waste —of dry cultivation—and of the beds of abandoned tanks; and one of the first difficulties that arose lay in the fact that Government land was in many cases divided or even cut off by inam and zamindari land, the proprietors of which showed great reluctance either to use the water themselves or to allow channels to pass through their property. By the terms of their tenure they reaped no direct benefit from the spread of irrigation, though the ryots who held under them of course would do so, and though they also suffered no harm they were unwilling to lend countenance to an improvement in which they saw no personal profit. The point of view was comprehensible but from it arose the necessity of much tact and persuasiveness to arrive at an amicable settlement, and a consequent delay in the expansion of irrigation. Some of the inamdars held out for a guarantee of permanent supply which of course could not be given, and others seemed to think that if the channels passed through their lands they would be able to take water without detection and without payment, or that if they held out the water would be given at a lower rate. The situation is by no means unique and is but one of the many reasons for the passing of an Irrigation Act. It is at present being arranged to bank the channels running through lands and tank-beds belonging to inamdars who refuse to take the water, and there seems no doubt that they will finally agree to allow their tenants to make use of it.

The custom of the Madura ryots has hitherto been to sow their first crop in October for the north-east monsoon and reap it in January, a very much smaller and more hazardous second crop being afterwards sown in February to be reaped in April. The Periyár water is however available in June and if used from then onwards is likely to run dry in March, necessitating a complete reconstruction of the habits of the people. In so conservative a race this is sure to take a considerable time, but it has already been done in a few isolated cases. There is necessarily a danger nevertheless that they will utilise the Periyár water, but under the old system, and if the rain comes late, at the end of November or beginning of December, their crops (which will then be nearly ripe) run the risk of being damaged. This is a difficulty which will set itself right in time. A more serious obstacle is the poverty of the country, which prevents the extension of irrigation on land hitherto dry and diminishes the second crop on customary wet lands. It is not a grazing country and is very devoid of trees, so that both leaf and animal manure is scarce, nor have the ryots capital or enterprise enough to remedy the defect by importing manure. This seems a case for the application of agricultural loans, and it would also probably be eventually profitable for the Government itself to become an importer of manure on a small scale in order to make its utility clearly manifest. Loans might also be usefully employed in enabling ryots to entertain the initial cost of converting dry land into wet. These views have already been accepted by the Government and it has further been suggested to allow a 50 per cent. reduction in water-rate for the first three years and 25 per cent. for the second three in all cases of conversion of dry to wet, and a remark has previously been made of the intention of the Government to dig free of cost all distributary channels irrigating more than 50 acres. Owing to the nature of the country these channels are far more difficult to lay out and costly to excavate than in delta districts. Long stretches of unoccupied and of inferior rocky or gravelly land have to be passed through by these channels, and until the water is brought close to the ryots and the supply shown to be reliable, it is too much to expect them to be forward in demanding it. This policy is therefore being actively pursued by the Government at present, and the result so far is distinctly encouraging and considerably in advance of the forecast. During the year 1896–97, the first year of settled supply, 50,106 acres of occupied wet were irrigated and 7,203 acres of second crop and of inam and zamindari lands, with 1,217 acres of new first crop and 5,225 acres of new second crop, the revenue amounting to Rs. 2,66,480, of which Rs. 2,31,348 must be deducted for existing assessment; and there seems no reason whatever to believe that the expansion will not be normal and uniform. The only contretemps has been the jamming of the sluices at the head of the tunnel, which has rendered it impossible to preserve any excess water (of which there was a large quantity) for the dry months of March, April and May. The loss is naturally under present circumstances of no moment, and arrangements have been made to substitute a Stoney's patent shutter at an early opportunity.

There are over 1,000 tanks in the Madura and Mélúr taluks affected by the Periyár channels, and pending further knowledge of the Periyár in a bad monsoon it would be rash to at once abandon such as are economically maintained, the more so that with complete utilisation of the water it is doubtful if a full supply would be available for more than two months after December even in a good monsoon; and in that case water stored previously in tanks would be very useful in March and April. Many tanks catching ordinary rainfall have therefore been retained, small and shallow tanks being generally abandoned, though exceptions have here and there been made in favour of some that were favourably situated for flood regulators or distributing reservoirs. Out of 320 tanks in the Madura taluk 80 have been for the present retained. The rest only irrigate 5,858 acres in all and have an area of 3,189 acres, of which over 2,000 can be cultivated. The loss of storage will be 16 per cent., which will be partly recouped by drainage running direct to other tanks. In Mélúr taluk nearly all the tanks are small and shallow and only 47 have been retained which will be reduced by amalgamation to 41. The sale of occupancy rights in the beds of abandoned tanks should produce a considerable sum. To fit them for cultivation the surplus works have been breached and the surplus channels deepened where necessary.

The branch channels and minor distributaries amount in aggregate length to * miles and * miles, respectively. A sluice or distributary has generally been placed between every two large nullahs, the course being usually on the crests of ridges; but deep and difficult excavation has been found unavoidable in some cases, and in others depressions have had to be crossed in which the channels have had to be heavily banked and the bed puddled. The average duty of water was taken at from 22 to 66 acres per cubic foot per second, according to the size of the channel, and in estimating the discharge a loss amounting to from ½ to 1 cubic foot a second was allowed for evaporation. The fall of the country being severe many drops were found requisite, and a bedfall of 6 feet per mile had generally to be adopted, 2 feet depth of water only being allowed so as to reduce the velocity. The characteristics which militated against easy distribution however enable the drainage of the country to be performed without any difficulty. The land commanded is bounded on the north by the main canal and on the south by the Vaigai river, between which all irrigation is conducted, so that a ready natural outflow for the drainage is provided. The total culturable area, according to a recent careful estimate, is—

	ACS.
Government land commanded by main canal and branches	80,816
Whole inam and zamin wet land	17,471
Lands under Chittanai	1,474
Total ..	99,761

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* Not yet complete

The retention of a number of tanks accounts for the deficit of 722 from the original estimate made by the Public Works Department, and the subsequent estimate made by the Revenue Department was far from correct. Should the water in the Periyár be found capable of irrigating more, the tunnel can be widened and irrigation readily extended on the south bank of the Vaigai, but in that case a new head sluice and distribution system will have to be constructed. It is, however, at present too early to enter into any examination of such a prospect.

APPENDIX.

A SLIGHT reference is necessary to the possibility of utilising the Periyár water for the development of power. After leaving the tunnel the water flows in the bed of a torrent down the side of the hills before it reaches the comparatively flat country of the Cumbum valley, and there is an available fall of some 900 feet in a length (measured along the bed of the stream) of about 6,800 feet. The question of the utilisation of this fall was referred in 1893 to a committee consisting of Colonel J. Pennycuick, Professor George Forbes, Professor W. C. Unwin, and Professor W. C. Roberts-Austen. This committee submitted an encouraging report, together with a list of the objects on which the power could be employed. These objects were—

Manufacture of carbide of calcium.
Manufacture of aluminium.
Electric traction on railways.
Cotton mills.
Electric lighting.

In 1897 a pamphlet was issued by the Government of Madras, giving the report of the committee in detail, together with a note by the Chief Engineer for Irrigation, and calling for tenders for the purchase of the right of developing and utilising the power. Up to the present moment no tenders have however been received, and it seems improbable that there will be any immediate demand for the concession.

TABLE I.

Table showing Monthly Quantities put into the Main Dam above zero level.

Month.	1891.		1892.		1893.		1894.		1895.	
	Rubble in mortar.	Concrete.	Rubble in mortar.	Concrete.	Rubble in mortar.	Concrete.	Rubble in mortar.	Concrete.	Rubble in mortar.	Concrete.
	C. FT.	C. FT.	C. FT.	C. FT.	C. FT.	C. FT.	C. FT.	C. FT.	C. FT.	C. FT.
January	...	...	24,000	87,100	71,968	75,611	45,888	126,462	57,119	127,586
February	...	...	55,670	92,427	63,843	89,411	43,981	126,376	62,948	121,506
March	...	...	63,000	81,000	37,317	59,021	17,543	...	61,311	114,784
April	...	...	...	...	36,999	24,640	...	...	...	...
May	...	...	19,333	...	...	...	36,417	35,443	...	...
June	...	...	...	...	...	...	...	...	...	...
July	...	50,000	16,863	1,678	7,185	29,028	35,825	49,603	42,745	67,324
August	16,000	53,000	17,953	...	7,010	68,159	49,525	111,007	87,182	71,066
September	27,000	36,000	63,151	2,092	14,407	111,818	49,477	99,239	98,894	49,339
October	12,000	39,000	57,466	22,534	23,064	113,984	52,593	104,404	52,523	49,541
November	34,779	29,586	73,720	72,223	34,406	114,207	63,135	135,546	57,980	27,302
December	26,072	97,858	74,105	84,830	40,382	124,245	55,902	129,286	...	...

TABLE II.—RATES.

Rates for Mortar, Main Dam.

Head works.

	RS.	A.	P.
1 parah surki powder	0	5	0
2 parahs slaked lime	1	6	0
3 ,, river sand	0	3	0
Mixing 4 parahs mortar obtained from foregoing	0	8	0
Supervision and sundries	0	2	0
For 4 parahs ..	2	8	0
For 1 parah ..	0	10	0

Rates for Concrete, Main Dam.

	RS.	A.	P.
100 cubic feet stone quarrying and stacking ..	6	8	0
Carriage to stone-breakers	1	8	0
Breaking to 2½" gauge	5	0	0
Carriage to dam	0	4	0
18 parahs mortar as above	11	4	0
Mixing and ramming	6	4	0
Carpenters, &c.	1	0	0
Supervision and sundries	0	4	0
For 100 cubic feet ..	32	0	0

Rates for Uncoursed Rubble Masonry, Main Dam.

	RS.	A.	P.
100 cubic feet stone quarrying and stacking ..	6	8	0
Carriage to dam	1	8	0
18 parahs mortar as above	11	8	0
Building (piece-work)	9	8	0
Supervision and sundries	1	8	0
For 100 cubic feet ..	30	4	0
For cement add ..	47	0	0

NOTE.—These rates are normal, but do not agree with the average for the main dam since much of the latter was very costly owing to difficult situations.

TABLE II.—Rates—*cont.*

Rates for Excavation.

		RS.	RS.
Tunnel, north end, water power.	Blasting	0·56	
	Drilling	4·53	
	Carpenters	0·29	
	Carriage of materials	0·16	
	Removing spoil	5·59	
	Smiths	1·50	
	Turbine	0·31	
	Extra for lead	1·40	
	Contingencies	0·24	
			14·58
	Rates for Explosives.		
	14·36 lb. gelatine	21·28	
	2·11 coils fuse	1·27	
	11·2 detonators	0·52	
			23·07
	Stores	10·00	
	Timber	2·31	
	Steel	0·25	
			12·56
	For 90 cubic feet = 1 foot run		50·21

NOTE.—This does not include prime cost of machinery or turbine channel, or reservoir.

Rates for Excavation.

		RS.	RS.
Tunnel No. 2 shaft, steam power.	Blasting	0·54	
	Drilling	11·54	
	Removing spoil	10·00	
	Smiths	2·04	
	Maintenance of machinery	0·49	
	Carriage of materials	0·12	
	Carpenters	1·08	
	Extra for lead	2·50	
	Contingencies	1·18	
			29·68

TABLE II.—Rates—*cont.*

Rates for Explosives.

		RS.	RS.
Tunnel No. 2 shaft, steam power—*cont.*	13·80 lb. gelatine	20·09	
	2·33 coils fuse	1·38	
	10·41 detonators	0·49	
			21·96
	Fuel	17·80	
	Timber	2·31	
	Stores	10·00	
	Steel	0·25	
			30·36
	For 90 cubic feet = 1 foot run		82·00

Note.—This does not include prime cost of machinery or communications. Hand power about the same as above.

Rates.

		RS.
Water-shed cutting. Rates for rock excavation.	Blasting	2·15
	Baling	8·00
	Carpenters	4·00
	Coolies	3·00
	Drivers and stokers	4·35
	Smiths	4·25
	Fuel	4·00
	Timber	2·00
	Steel	2·25
	Removal of rock (piece-work)	80 to 90
	Total	114 to 124 per 1,000 cubic feet.

Rates for Transport of Limestone.

	RS.	A.	P.
Ropeway up ghat per 100 cubic feet	3	4	0
Canal, 6 miles	4	4	0
Quarrying and carting, 8½ miles to canal.	16	8	0
Do. Do. 14 miles to kilns	27	8	0

Note.—The baling refers to hand baling only. The engines were applied to both pumping and raising spoil.

TABLE II.—Distribution Works.

Rates of Labour or Material.

	RS. A. P.	
Maistry	15 0 0 to 25 0 0	per mensem.
Stone-cutter	0 8 0 to 0 12 0	per day.
Cooly man	0 4 0	per day.
Cooly woman	0 2 0	do.
Cooly boy	0 1 6	do.
Picottah man	0 4 0	do.
Bullocks (pair)	0 12 0	do.
Burnt stone, quarried and stacked	8 0 0	per 100 cub. ft.
Stone slabs, roughly split	30 0 0 to 50 0 0	do.
Palmyra rafters	125 0 0 to 175 0 0	per 100.
Vengai wood	2 8 0	per cub. ft.
Clearing light jungle	0 2 6	,, 100 sq. ft.
Clearing prickly-pear	0 2 6	,, do
Blasting rock	5 0 0	,, 100 cub. ft. (solid).
Earthwork	3 0 0 to 6 0 0	per 1,000 cub. ft.
Earthwork in stony ground	8 0 0 to 14 0 0	do.
Puddle wall	2 2 0	per 100 cub. ft.
Turfing, including watering	0 8 0	,, 100 sq. ft.
Concrete	14 8 0 to 16 0 0	per 100 cub. ft.
Brickwork, in clay	10 0 0	do.
Brickwork, in mortar	21 0 0	do.

TABLE II.—DISTRIBUTION WORKS—*cont.*

Rates of Labour or Material—cont.

	RS.	A.	P.		
Ashlar, in mortar	1	0	0	per	1 cub. ft.
Coursed rubble, in mortar	20	0	0	,,	100 cub. ft.
Coursed rubble, in mortar, archwork ..	23	0	0	,,	do.
Rubble revetment	10	8	0	,,	do.
Plastering	2	8	0	,,	100 sq. ft.
Pointing	1	8	0	,,	do.
Whitewashing	0	4	0	,,	do.
Tiled roofing	14	8	0	,,	do.
Teakwood, wrought and put up, small ..	3	8	0	,,	1 cub. ft

TABLE III.

List of Floating Plant.

1 steam-tug, 60-H.P.
1 ,, 35-H.P.
1 ,, 15-H.P.
1 oil launch, 8-B.H.P.
1 floating, 400-ton, Priestman's steam dredger
1 ,, 100-ton, locally-made ,,
2 50-ton wooden barges.
4 20-ton steel barges.
13 35-ton wooden barges.
11 30-ton ,,
8 20-ton ,,
4 15-ton ,,

TABLE IV.—Rain Register.

Day of month.	1888. January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	...	...	...	·60	1·10	·75	·37	·33	...	·30	·35
2 ...	...	...	...	...	·90	·85	·75	·01	·02	...	·62	·35
3 ...	...	...	...	...	·75	2·20	...	1·05	·08	...	·24	·90
4 ...	...	...	...	...	·80	·90	·45	·10	...	·10	·24	...
5 ...	...	...	...	...	1·40	1·75	·25	·50	...	...	·50	...
6 ...	...	...	...	...	1·10	1·20	1·00	·07	...	...	...	...
7 ...	...	...	...	...	·70	1·80	1·40	·20	·02	...	...	...
8 ...	...	...	·12	...	·40	2·10	3·50	·35	...	...	1·00	...
9 ...	...	...	·05	...	·95	1·70	1·85	·05	...	·75	·13	...
10 ...	...	...	1·85	...	·75	·80	1·25	·24	...	...	·70	...
11 ...	...	...	·57	·75	1·20	1·05	·55	·38	·97	...	·73	...
12 ...	...	...	...	·85	·40	0·75	...	·30	...	·03	...	...
13 ...	...	...	...	·60	·60	2·10	·05	...	1·47	...	...	...
14 ...	...	...	...	1·05	1·30	·80	·12	...	·13	1·07	...	...
15 ...	...	...	...	·60	·15	·90	...	·26	·37	...	...	...
16 ...	...	...	...	·75	2·5	·70	·25	·04	·43	·09	...	2·05
17 ...	...	...	...	·75	...	1·10	·15	·02	...	·18	...	...
18 ...	...	...	...	·95	...	·70	...	·25	1·90	·07	...	...
19 ...	...	...	...	...	...	·60	·02	·35	·10	...	...	...
20 ...	...	...	...	·25	·75	·20	...	·20	...	·23	...	...
21 ...	...	...	...	...	·80	·05	·05	·75	...	·26	...	...
22 ...	...	...	...	...	·70	...	·05	·85	1·35	...	...	...
23 ...	...	...	...	·40	·90	·05	·27	·10	·76	...	...	...
24 ...	...	...	...	·55	...	...	·45	·02	·15	...	...	...
25 ...	...	...	...	·85	...	·18	·24	·05	·56	·13	...	...
26 ...	...	...	...	·35	...	·40	·15	·12	·08	·23	·84	...
27 ...	...	...	...	·65	...	1·90	·18	·14	·04	1·33	...	...
28 ...	...	...	...	·35	...	·68	·15	·16	·25	·20	·15	...
29 ...	...	...	...	·35	·15	·64	·55	·07	·38	·53	...	...
30 ...	...	...	...	·45	·20	·13	·45	·50	·20	·23	...	...
31 ...	...	...	...	...	·30	...	·15	·05	...	·25	...	...
Total for month.	...	...	...	9·75	17·25	27·53	14·28	7·55	9·59	5·68	5·45	3·65
	Total for 1888 ... 100·73											

TABLE IV.—RAIN REGISTER—*cont.*

Day of month.	1889.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	...	...	...	·35	·80	·15	·20	...	·04	...	...
2 ...	...	...	·28	...	·20	...	·25	·50	...	·17	...	...
3 ...	...	...	...	·20	...	·80	·05	...	·80	·08	1·30	...
4 ...	...	...	...	·60	·50	·60	·10	·20	·07	·36	·57	...
5 ...	...	...	...	...	·85	·15	·20	·30	·18	·11	...	...
6 ...	...	...	...	...	...	...	·25	·45	·05	·33	·11	...
7 ...	...	...	...	...	...	·85	·35	2·55	...	·03	·28	...
8 ...	...	...	...	·80	·65	·30	·15	1·15	...	·03	...	...
9 ...	...	...	...	...	·35	·20	·45	·50	...	·40	...	...
10 ...	...	...	...	...	·60	·60	·25	·45	...	·06	...	...
11 ...	...	...	...	...	·55	·25	·30	·15	1·50	·12	...	...
12 ...	...	...	...	...	...	·25	1·60	·10	·08	·25	...	...
13 ...	...	...	...	...	...	·05	·05	·15	·52	·94	...	...
14 ...	...	...	...	...	...	·55	·05	·15	·14	·84	·59	...
15 ...	...	...	...	...	...	·50	·90	·20	·24	1·52	·53	...
16 ...	...	...	...	...	...	·45	1·70	·25	1·28	1·40	...	...
17 ...	...	...	...	...	...	·30	1·50	·70	1·15	1·84	·31	...
18 ...	...	...	...	...	·55	1·30	1·70	·85	2·20	1·69	·14	·07
19 ...	...	...	...	...	...	1·25	2·05	·65	1·51	·20	·34	3·15
20 ...	...	·55	...	...	...	·50	...	·40	·39	·10	·01	·20
21 ...	...	·27	...	...	...	·30	...	·65	·37	...	...	·11
22 ...	...	...	2·19	·50	...	·25	·05	·80	·05	·09	...	...
23 ...	...	·43	...	...	...	...	...	·55	·20	·05	...	...
24 ...	...	...	...	2·55	...	...	·15	·05	·25	...	...	...
25 ...	...	...	...	2·30	...	...	...	·10	·02	...	·42	...
26 ...	...	...	...	3·00	...	·35	·70	·90	·02	...	·25	...
27 ...	...	...	...	2·10	...	·25	·25	·65	·10	...	·04	...
28 ...	...	...	·20	·80	·63	·65	·15	·15	·20	...	...	...
29 ...	...	...	·02	·15	...	·25	·25	·20	·02	...	...	...
30 ...	...	...	·04	·50	...	·05	·05	·10	·01	...	...	...
31 ...	...	...	·04	...	...	...	·05	·10	...	...	...	...
Total for month.	...	1·25	2·77	14·20	5·23	11·80	14·15	14·15	11·35	10·65	4·89	3·53
	Total for 1889 ... 93·97											

TABLE IV.—Rain Register—*cont.*

Day of month.	1890.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	...	...	...	...	·16	·20	·22	·01	...	·36	...
2 ...	...	...	·18	...	...	...	...	·16	...	...	·04	...
3 ...	...	...	·13	...	...	·32	...	·08	·01	·08	·15	·05
4 ...	...	...	·44	...	...	...	...	·35	·06	·18	·20	·02
5 ...	...	...	·11	...	...	·15	...	·41	·36	·02	·01	·24
6 ...	...	...	·19	...	...	·05	...	·34	·20	...	·07	...
7 ...	..	...	·15	...	...	...	·10	·35	·07	...	·05	...
8 ...	...	...	·05	·13	...	...	·30	1·50	·02	·01	...	...
9 ...	·50	...	·04	·24	...	·20	·25	·38	·04	·09	·72	...
10 ...	...	...	·09	...	...	·14	·08	·20	·69	·95	·04	...
11 ...	...	...	...	...	...	·25	·25	·19	·05	·51	·02	·01
12 ...	...	...	...	...	...	·21	·18	·17	·40	·08	·07	·01
13 ...	...	...	...	...	...	·41	·24	·13	·28	·08	·02	...
14 ...	...	...	...	1·15	·05	·99	·52	·02	·20	·36	...	...
15 ...	...	...	...	1·15	·05	1·12	·54	...	·14	·47	·04	...
16 ...	...	...	1·10	·37	...	·47	·02	...	·19	·41	·01	...
17 ...	...	...	...	...	...	1·55	·09	·04	·15	...	...	...
18 ...	...	...	·04	...	·04	·70	·22	·01	...	·04	..	...
19 ...	...	...	...	·35	·53	·52	·16	·10	...	·32	...	...
20 ...	...	...	...	·25	...	...	1·34	...	...	...	...	...
21 ...	...	...	...	·72	...	...	1·83	·02	...	·30	...	·02
22 ...	...	...	...	·15	·07	1·06	1·11	...	·05	·65	...	...
23 ...	...	...	...	1·39	...	·31	1·00	·09	·06	·12	·01	...
24 ...	...	·39	...	...	...	·04	·70	·21	·09	·24	...	...
25 ...	...	·22	...	·12	·02	...	·09	·13	·01	·35	...	...
26 ...	...	·20	...	·15	...	...	·56	·04	...	·78	...	...
27 ...	...	...	...	...	...	·24	·48	·05	·05	1·53	...	...
28 ...	...	...	·18	1·50	·37	·33	·02	·02	·17	2·43	...	...
29 ...	...	...	...	...	...	·61	·10	·26	·01	·14	·13	...
30 ...	...	...	...	...	...	·07	1·01	·11	...	·20	·40	...
31 ...	...	...	.	...	...	...	·21	...	...	·24	...	...
Total for month.	·50	·81	2·70	8·16	1·53	9·90	11·60	5·58	3·31	10·58	2·33	·35
	Total for 1890 ... 57·55											

TABLE IV.—Rain Register—*cont.*

Day of month.	1891.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 …	…	…	…	…	…	·45	·78	·15	·04	·57	…	…
2 …	…	·03	…	…	…	·14	·84	·15	·09	·64	1·01	…
3 …	…	·03	…	…	·02	·60	·75	·50	·35	·36	1·51	…
4 …	…	·02	…	…	·06	·93	·80	·46	·30	·53	·75	…
5 …	…	·02	…	…	…	·41	·45	·09	·14	·13	·56	…
6 …	…	·04	…	·40	·11	·45	·67	·03	·49	·09	·12	…
7 …	…	·01	·17	·19	…	·16	·09	…	·03	·31	…	…
8 …	…	…	·04	·30	·05	·65	·06	…	·04	·06	…	…
9 …	·01	…	…	·70	·06	2·55	·09	…	…	·01	…	…
10 …	…	…	…	·20	·06	·77	…	·10	·01	·03	·84	…
11 …	…	·10	…	…	·01	1·22	·14	·10	…	·60	·40	…
12 …	…	·44	·29	·20	·12	·92	·15	·13	…	·73	·04	…
13 …	…	·02	·11	…	…	1·82	·10	…	·23	·20	·40	·18
14 …	…	·28	·14	…	…	·05	·06	…	·05	·49	·12	·08
15 …	…	·19	·12	…	·09	…	·44	·01	…	·11	·60	…
16 …	…	·09	1·15	…	·10	…	·58	…	…	·59	·40	…
17 …	…	·03	·29	1·45	·15	·16	·10	…	…	·21	…	…
18 …	…	…	…	·01	·10	…	…	·02	·07	·42	…	…
19 …	…	…	…	…	·54	·11	·67	·09	…	·28	…	…
20 …	·05	·05	…	…	·41	·14	1·94	·17	…	·90	…	·03
21 …	·10	·13	…	·07	·40	·05	1·28	·13	…	·82	…	·07
22 …	…	·04	…	·25	·26	·10	1·96	·27	…	·77	…	…
23 …	…	·12	…	·19	…	·54	1·40	·84	…	·40	…	…
24 …	…	·05	…	·02	·04	·29	·53	·19	…	…	…	…
25 …	…	…	…	·11	·11	·16	·50	·53	…	·23	…	…
26 …	…	…	…	·10	…	·10	·24	·22	…	·20	·33	…
27 …	…	…	…	·08	·05	·03	1·00	·03	·01	·46	…	…
28 …	…	…	…	1·01	…	·15	·77	·10	1·01	…	·04	…
29 …	…	…	…	·06	·04	·53	·36	·07	…	·67	·01	…
30 …	…	…	…	·11	·16	·50	·22	·63	…	·06	…	…
31 …	…	…	…	…	…	…	·15	·08	…	·73	…	…
Total for month.	·16	1·69	2·31	5·51	2·94	13·92	17·12	5·09	1·85	12·60	7·13	0·36
	Total for 1891 … 70·68											

TABLE IV.—Rain Register—*cont.*

Day of month.	1892.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	...	...	...	...	·35	...	·26	·02	·21	...	...
2 ...	...	...	...	...	...	·38	·38	·11	...	·09	...	·02
3 ...	·01	...	...	...	·02	·65	·20	·10	·01	·14	...	...
4 ...	...	...	...	...	...	...	·45	·44	·01	·09	·15	...
5 ...	...	...	...	...	...	·07	...	·33	·01	·50	·01	...
6 ...	...	...	...	...	·13	·35	...	·32	...	...	...	...
7 ...	...	...	...	...	...	·70	...	·73	...	·06	·95	...
8 ...	...	...	...	...	...	1·55	...	·27	·01	·02	·12	...
9 ...	...	...	...	·82	·38	1·86	...	...	..	...	...	...
10 ...	...	...	...	·44	...	1·09	...	·21	·11	...	·03	...
11 ...	...	...	...	...	...	·13	...	·02	·07	...	...	...
12 ...	...	·01	·01	·90	...	...	...	·05	·08	·30	...	...
13 ...	...	·05	·05	·07	...	..	...	·04	·15	·44	...	...
14 ...	...	·01	·01	·54	...	...	...	·06	·05	·09	·08	...
15 ...	...	·01	·01	·06	...	...	...	·11	...	·07	·02	...
16 ...	...	...	..	...	...	...	5·16	·15	·03	·02	...	...
17 ...	...	...	...	...	...	...	·11	1·05	...	·84	...	·47
18 ...	...	...	...	·03	...	...	·05	·11	·03	·33	...	...
19 ...	...	...	...	...	...	...	·24	·01	·09	·13	...	·01
20 ...	...	...	...	...	...	...	1·45	·25	·04	·19	...	...
21 ...	...	...	...	...	...	...	1·67	·18	·05	·53	·01	...
22 ...	...	...	...	·51	...	...	1·93	·57	·01	·90	..	...
23 ...	...	...	...	1·92	·04	...	1·21	·13	·07	·11	...	...
24 ...	...	...	...	·27	·37	...	7·26	·64	·02	·18	...	...
25 ...	...	...	...	·13	·20	·90	·81	·35	·06	·08	...	...
26 ...	...	...	...	...	·58	·88	1·09	·20	·07	·34	...	...
27 ...	...	·02	·02	...	...	...	·51	·08	·48	·02	...	...
28 ...	...	·30	·30	...	...	...	·25	·48	·30	·40	...	...
29 ...	...	·03	·03	...	...	...	·17	·08	·18	·13	...	...
30 ...	...	...	...	...	·42	...	·10	·16	·44	·06	...	...
31 ...	...	...	...	...	·46	...	·37	·01	...	...	...	...
Total for month.	·01	·43	·43	5·69	2·57	8·91	23·41	7·60	2·39	6·27	1·37	·50
	Total for 1892 ... 59·58											

TABLE IV.—Rain Register—*cont.*

Day of month.	1893.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	..	·07	...	·06	...	·60	3·05	·18	·27	·13	...
2 ...	...	...	·10	...	...	·40	...	1·20	·01	...	·38	...
3 ...	...	...	...	...	...	·27	·15	·80	·01	·15	...	...
4 ...	...	...	...	...	...	·17	·08	·85	·35	·65	...	...
5 ...	...	...	·15	...	·55	·31	·25	·55	·47	·21	·15	...
6 ...	...	...	·28	·08	1·09	·43	·09	·12	·44	·12	...	...
7 ...	...	...	·02	·02	·15	·02	·25	·45	·09	·13	·41	...
8 ...	...	...	...	·27	1·15	·41	·62	·22	·27	·43	·66	...
9 ...	·10	...	...	...	·20	1·24	...	·17	·09	·16	·60	...
10 ...	...	...	...	...	·07	2·41	·10	...	·22	·12	·41	...
11 ...	...	...	...	...	·06	1·31	·23	...	·43	·27	·10	...
12 ...	...	...	...	...	...	·48	·25	·02	·53	·16	·06	...
13 ...	...	...	...	...	...	·38	...	·15	·30	1·75	·33	...
14 ...	...	...	...	...	·85	1·02	...	...	·32	1·09	·45	...
15 ...	...	...	...	...	·10	1·82	·25	...	·12	·61	·38	...
16 ...	...	...	...	...	...	3·80	·50	·04	...	·36	·15	...
17 ...	·65	...	...	...	·35	1·65	...	...	...	·87	·15	...
18 ...	·06	·01	...	...	·32	...	·05	·13	...	·01	·03	...
19 ...	·07	·01	...	...	...	...	·28	·15	...	·05	·01	...
20 ...	...	·03	...	...	·02	·45	·19	·17	...	·03	...	...
21 ...	...	·81	...	·25	·07	·95	·10	...	·04	·40	...	...
22 ...	...	·55	·05	...	·09	·50	·04	·15	...	·17	·12	...
23 ...	...	...	...	...	·05	...	·07	·23	...	...	·03	...
24 ...	...	·02	·08	...	...	·35	·29	·08	...	...	...	...
25 ...	...	·04	...	...	·66	·70	·82	·40	...	·86	·35	...
26 ...	..	·31	·11	..	·45	·48	·16	·09	...	·13	·08	...
27 ...	...	...	·12	...	·34	·10	·74	·09	...	·89	·44	...
28 ...	...	...	...	...	·40	...	1·12	·16	...	·05	...	...
29 ...	...	...	...	...	·24	...	1·00	·13	...	·16	...	...
30 ...	...	...	...	...	·12	1·03	·35	·19	...	·15	...	...
31 ...	...	...	...	...	...	...	·80	·08	...	...	...	...
Total for month.	·88	1·78	·91	·71	7·39	12·66	8·88	9·67	3·87	10·25	5·33	...
	Total for 1893 ... 62·33											

TABLE IV.—Rain Register—*cont.*

Day of month.	1894.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	...	...	·37	...	·02	·15	·07	·20	...	·65	·15
2 ...	...	...	...	...	...	...	·02	·05	...	·28	·60	...
3 ...	...	·03	...	·27	...	·02	·45	·25	...	·42	·15	·15
4 ...	...	·65	...	1·67	·27	·06	·35	·25	...	·72	...	...
5 ...	...	...	...	...	...	·45	·10	·27	...	...	·05	...
6 ...	...	...	...	...	·05	·77	·43	1·10	·08	...	·15	·15
7 ...	...	...	...	·10	...	·50	·03	·55	·30	...	·65	...
8 ...	...	...	...	·85	...	·25	·10	·08	1·10	...	·15	...
9 ...	...	...	...	...	·12	·15	·25	·22	·20	...	...	...
10 ...	...	...	...	...	...	·10	1·10	·63	·23	...	·10	...
11 ...	...	...	...	·72	...	·50	1·00	·45	...	...	...	...
12 ...	...	...	...	...	·63	·30	·15	·35	·50	·62	·05	...
13 ...	...	...	...	...	...	1·01	·05	·02	...	·06	...	...
14 ...	·18	...	...	...	...	·35	·45	·18	...	...	...	...
15 ...	...	...	...	·10	...	·50	·95	·40	·05	·60	·11	...
16 ...	...	...	...	·12	...	·55	·22	·43	·66	·03	·15	...
17 ...	...	...	1·15	...	...	1·00	1·15	1·00	·10	...	·07	...
18 ...	...	...	...	·20	...	1·10	1·70	·08	·01	2·13	...	...
19 ...	...	...	1·25	...	...	1·10	2·90	·20	·31	·40	·15	...
20 ...	...	...	·18	·25	...	2·00	2·00	·12	...	1·30	·02	...
21 ...	...	...	·20	...	...	1·45	1·15	·05	...	1·60	...	...
22 ...	...	...	...	...	...	·40	·20	·52	·12	·57	...	...
23 ...	...	...	...	...	·01	·30	·35	·20	·06	2·42	...	...
24 ...	...	...	...	...	·05	·60	·18	·10	·28	·55	...	...
25 ...	...	...	...	...	·60	·25	·05	·85	·05	·06	...	...
26 ...	...	...	·65	...	...	·08	·40	·03	·30	...	...	...
27 ...	...	...	·08	·62	...	...	·22	·28	·06	·05	...	...
28 ...	...	...	...	·15	...	·12	·05	1·00	·03	·02	...	...
29 ...	...	...	...	·42	...	·08	·03	·32	...	·20	...	...
30 ...	...	...	...	·85	...	·03	...	·45	·05	...	...	...
31 ...	...	...	...	...	·25	...	·02	·35	...	·46	...	...
Total for month.	·18	·68	3·51	6·69	1·98	14·04	16·20	10·85	4·69	12·49	3·05	·45
	Total for 1894 ... 74·81											

TABLE IV.—RAIN REGISTER—*cont.*

Day of month.	1895.											
	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1 ...	...	...	...	...	...	...	3·50	·33	·08	·27	1·45	...
2 ...	...	...	...	...	...	...	·25	·24	·35	·04	·84	...
3 ...	...	...	...	...	...	...	·05	...	·05	...	1·42	·38
4 ...	...	...	...	·35	...	...	1·00	·05	·04	...	·62	...
5 ...	...	...	...	·45	·10	...	·10	·32	...	...	·94	...
6 ...	...	...	...	·20	·05	...	·25	·08	·02	·08	1·05	...
7 ...	...	...	...	...	...	1·00	·05	·03	·02	·04	·08	...
8 ...	...	...	...	...	·45	...	·50	1·49	...	·35	...	...
9 ...	...	...	...	·02	...	...	·30	·64	·05	1·18	...	...
10 ...	...	...	...	·22	...	...	1·00	·10	·05	...	·01	...
11 ...	...	...	...	·80	...	1·45	·80	·02	...	...	...	...
12 ...	...	...	...	1·15	...	·70	·10	...	...	·27	...	...
13 ...	...	...	...	2·10	1·25	·60	·60	·85	...	·10	...	...
14 ...	...	...	...	·05	·65	1·05	·80	·16	·05	·23	...	...
15 ...	...	...	...	...	...	·05	·08	·14	·20	·12	...	...
16 ...	...	...	...	...	·50	·25	...	·02	·31	·12	...	...
17 ...	...	...	...	...	...	·90	·12	...	·11	·19	...	...
18 ...	...	...	...	...	...	3·05	·22	1·06	...	1·01	...	...
19 ...	...	...	...	1·60	...	4·50	·05	·08	·04	·05	...	...
20 ...	...	...	...	·05	...	4·55	·94	·10	·14	·39	·02	...
21 ...	...	...	...	·15	·03	2·40	·64	·56	·25	3·62	...	...
22 ...	...	...	...	·12	·10	1·15	·07	·63	·13	·30	...	...
23 ...	...	...	...	·05	...	·63	·08	·17	·01	1·00	·01	...
24 ...	...	...	...	...	...	·07	·34	·35	...	·60	...	...
25 ...	...	...	...	...	...	·43	·27	·45	...	·14	...	...
26 ...	...	...	...	·35	...	·35	·54	·06	·09	·01	...	...
27 ...	...	...	...	...	...	·12	·20	·25	...	·27	...	·05
28 ...	...	...	...	·90	...	·60	·74	·07	·43	·04	...	·30
29 ...	...	...	...	...	·55	·50	·67	...	1·36	...	...	·90
30 ...	...	...	...	...	...	·73	·10	·12	·61	·21	...	1·08
31 ...	...	...	...	...	·25	...	·25	·31	...	·09	...	...
Total for month.	...	...	...	8·56	3·93	25·08	14·59	8·68	4·32	10·72	6·44	2·71
	Total for 1895 ... 85·03											

TABLE V.

Average, Maximum and Minimum Discharges during each month from July to February.

Month.	Cubic feet per second.						
	Average.					In four seasons.	
	1869–70.	1870–71.	1871–72.	1872–73.	Mean.	Maximum.	Minimum.
July	1,085	...	2,980	...	2,032	13,110	522
August ...	1,235	...	864	1,195	1,098	7,272	425
September ...	842	...	812	1,266	973	5,845	425
October ...	857	1,344	941	582	931	7,644	347
November ...	6,205	1,525	1,531	...	3,088	127,129	404
December ...	1,212	554	689	...	818	12,874	311
January ...	680	1,207	335	...	741	12,994	270
February ...	342	372	311	...	342	731	200

TABLE VI.

Estimate of Rainfall in the Periyár Valley.

Month.	Average recorded rainfall at				Average depth run off from Periyár catchment, 1868–72.	Estimated rainfall at 1·8 depth run off.	Depth run off.	Rainfall.
	Cochin.	Trivandrum.	Angustermally.	Average.			To give the discharges entered in column 4 of Table VII.	
	INCHES.	INCHES	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.
January ...	0·34	0·56	6·23	2·38	2·92	5·26	2·86	5·15
February ...	0·65	0·39	2·28	1·11	1·54	2·77	1·15	2·07
March ...	1·93	1·91	3·18	2·34	...	...	1·24	2·23
April ...	5·30	5·48	7·41	6·06	...	...	2·15	3·87
May ...	13·34	8·87	30·66	17·62	...	...	5·74	10·33
June ...	28·05	11·84	28·64	22·84	...	...	7·17	12·91
July ...	22·47	8·28	30·96	20·57	7·81	14·06	7·17	12·91
August ...	12·77	6·11	21·86	13·58	4·22	7·60	4·16	7·49
September.	8·48	4·44	16·46	9·79	3·63	6·53	3·59	6·46
October ...	12·63	10·05	26·04	16·24	3·29	5·92	3·16	5·69
November.	4·32	5·56	15·58	8·49	11·34	20·41	7·17	12·91
December ...	0·88	1·52	9·72	4·01	3·18	5·72	3·01	5·20
Total ...	111·16	65·01	199·02	125·03	...	...	48·57	87·44

TABLE VII.

Estimate of Water available for Irrigation.

Month.	Average discharge as gauged, 1868–72.	Discharge from 300 square miles, $\frac{5}{6}$ of the depths in col. 5 of Table VI.	Estimated discharge.	Loss by evaporation		Balance available for irrigation.
				On Periyár lake.	In beds of Surúli and Vaigai.	
	Millions of cubic feet.					
January ...	2,020	921	2,000	150	100	1,750
February ...	836	430	800	180	90	530
March ...	...	905	900	220	90	590
April ...	...	2,346	1,500	220	...	1,280
May	...	6,822	4,000	180	† 590	3,230
June	...	8,844	* 4,000	110	80	3,810
July	5,440	7,965	* 4,000	80	100	3,820
August ...	2,941	5,259	2,900	110	100	2,690
September ...	2,525	3,791	2,500	150	90	2,260
October ...	2,294	6,288	2,200	110	80	2,010
November ...	8,002	3,287	6,000	110	80	5,810
December ...	2,193	1,553	2,100	120	90	1,890
Total ...	...	48,411	32,900	1,740	1,490	29,670

* The discharge during these months will exceed 4,000 millions of cubic feet, but a portion may be lost by discharge over the escape.

† 500 millions are allowed for filling the beds of the Surúli and Vaigai rivers.

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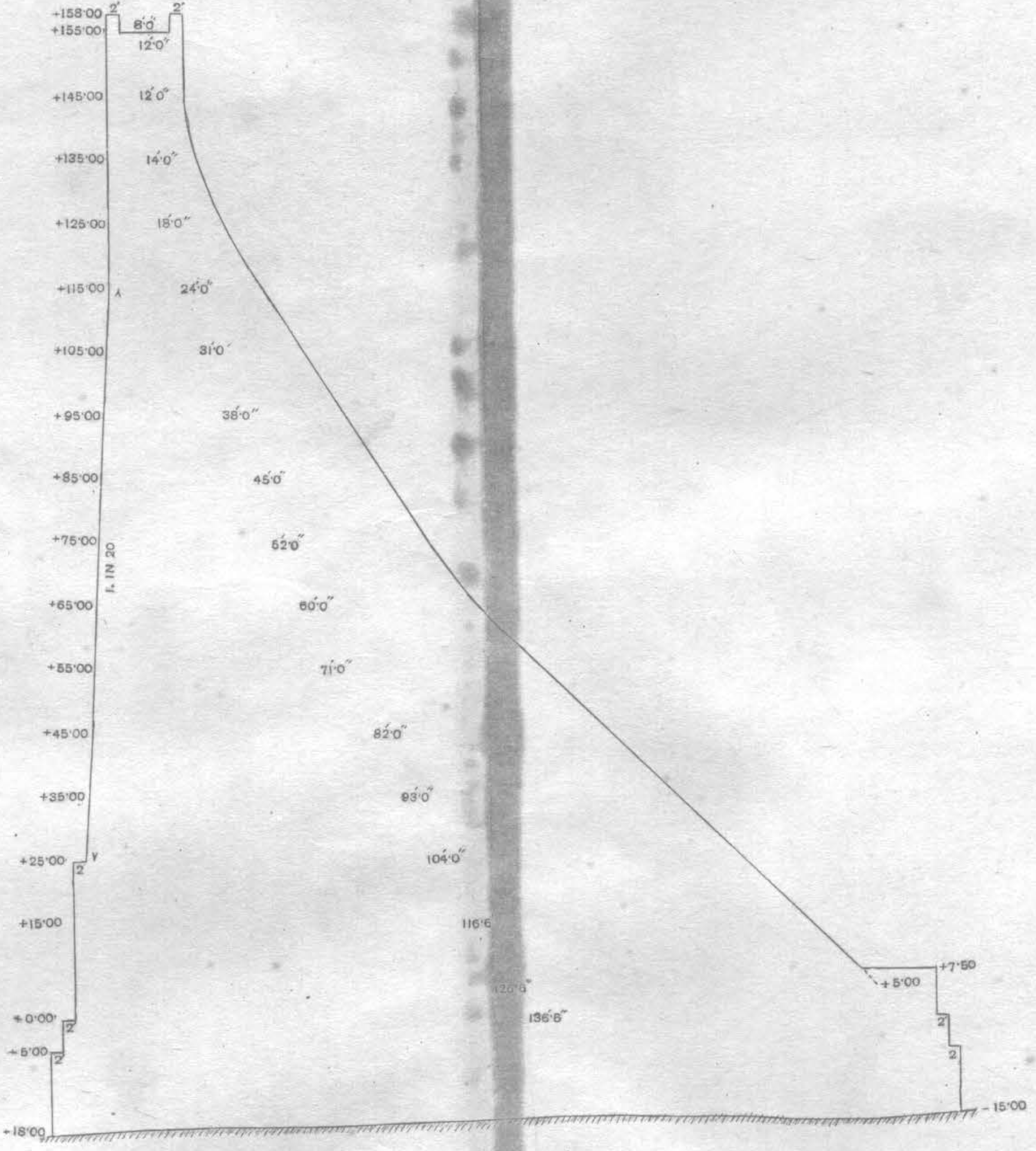
PLATE.IV



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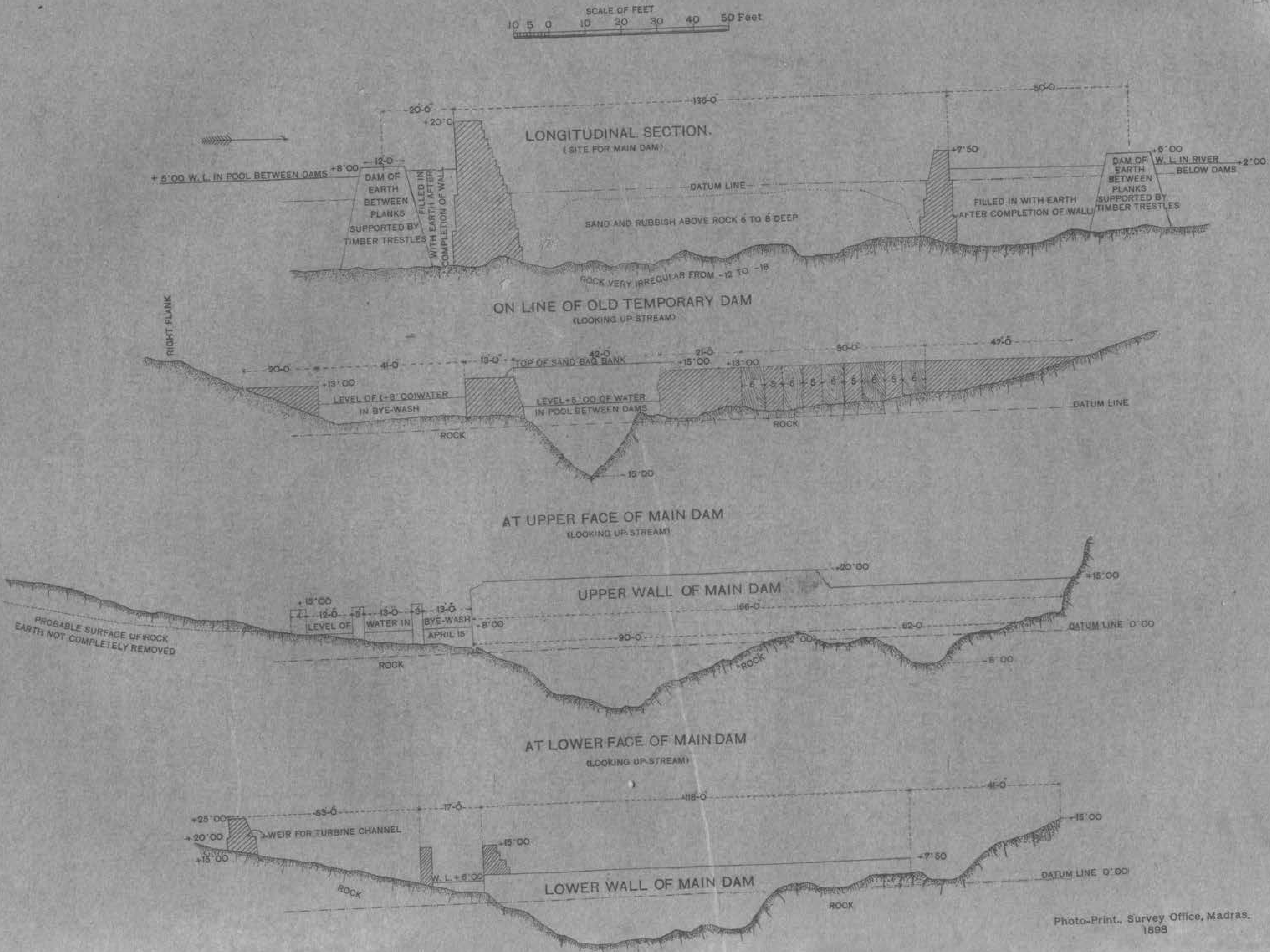
PERIYAR PROJECT WORKS
SECTIONS OF THE MAIN AND TEMPORARY DAMS
ACROSS PERIYAR RIVER.

PLATE NO IV



LONGITUDINAL SECTION.
(SITE FOR MAIN DAM)

ON LINE OF OLD TEMPORARY DAM
(LOOKING UP-STREAM)

AT UPPER FACE OF MAIN DAM
(LOOKING UP-STREAM)

AT LOWER FACE OF MAIN DAM
(LOOKING UP-STREAM)

SCALE OF FEET
10 5 0 10 20 30 40 50 Feet
20-0
136-0
50-0
+20'0
+8'00
12-0
+ 5'00 W. L. IN POOL BETWEEN DAMS
DAM OF EARTH BETWEEN PLANKS SUPPORTED BY TIMBER TRESTLES
FILLED IN WITH EARTH AFTER COMPLETION OF WALL
DATUM LINE
SAND AND RUBBISH ABOVE ROCK 6 TO 8 DEEP
ROCK VERY IRREGULAR FROM -12 TO -18
+7'50
+5'00
W. L. IN RIVER BELOW DAMS
+2'00
FILLED IN WITH EARTH AFTER COMPLETION OF WALL
DAM OF EARTH BETWEEN PLANKS SUPPORTED BY TIMBER TRESTLES
RIGHT FLANK
20-0
41-0
13-0
42-0
21-0
50-0
47-0
TOP OF SAND BAG BANK
+15'00
+13'00
+13'00
6 5 6 5 6 5 6 5 6
LEVEL OF (+8'00) WATER IN BYE-WASH
LEVEL +5'00 OF WATER IN POOL BETWEEN DAMS
ROCK
ROCK
DATUM LINE
-15'00
PROBABLE SURFACE OF ROCK EARTH NOT COMPLETELY REMOVED
+15'00
4
12-0
3
13-0
3
13-0
LEVEL OF WATER IN BYE-WASH APRIL 15
-8'00
ROCK
UPPER WALL OF MAIN DAM
+20'00
166-0
+15'00
90-0
62-0
DATUM LINE 0'00
ROCK
-8'00
+25'00
+20'00
+15'00
63-0
17-0
118-0
41-0
WEIR FOR TURBINE CHANNEL
+15'00
W. L. +6'00
ROCK
LOWER WALL OF MAIN DAM
+7'50
+15'00
DATUM LINE 0'00
ROCK

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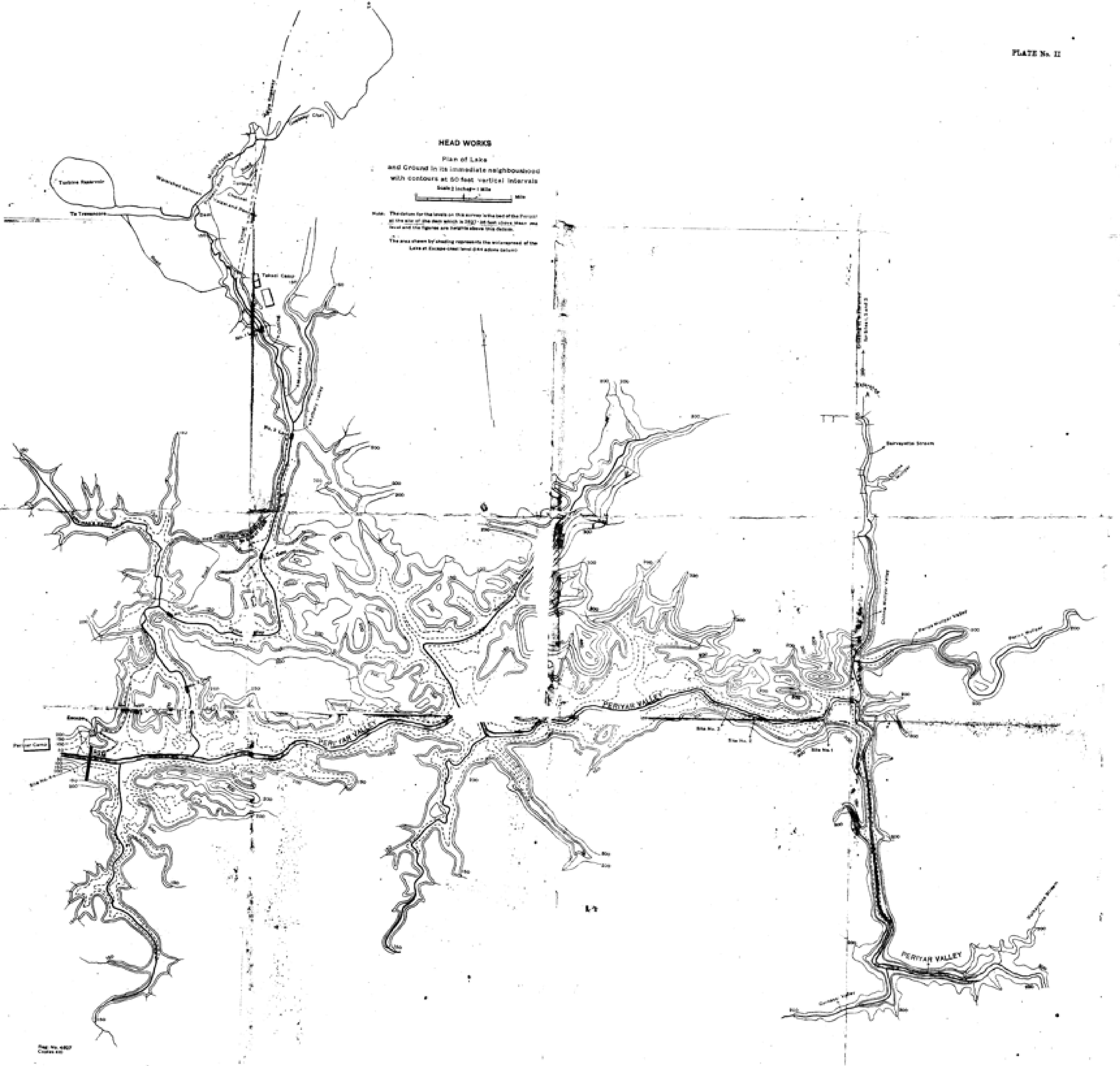
PLATE No. II

HEAD WORKS

Plan of Lake
and Ground in its immediate neighbourhood
with contours at 50 feet vertical intervals
Scale 2 inches = 1 Mile



Note: The datum for the levels on this survey is the bed of the Periyar at the site of the dam which is 2827·36 feet above mean sea level and the figures are heights above this datum.

The area shown by shading represents the water-spread of the Lake at Escape-sill level (155 above datum).

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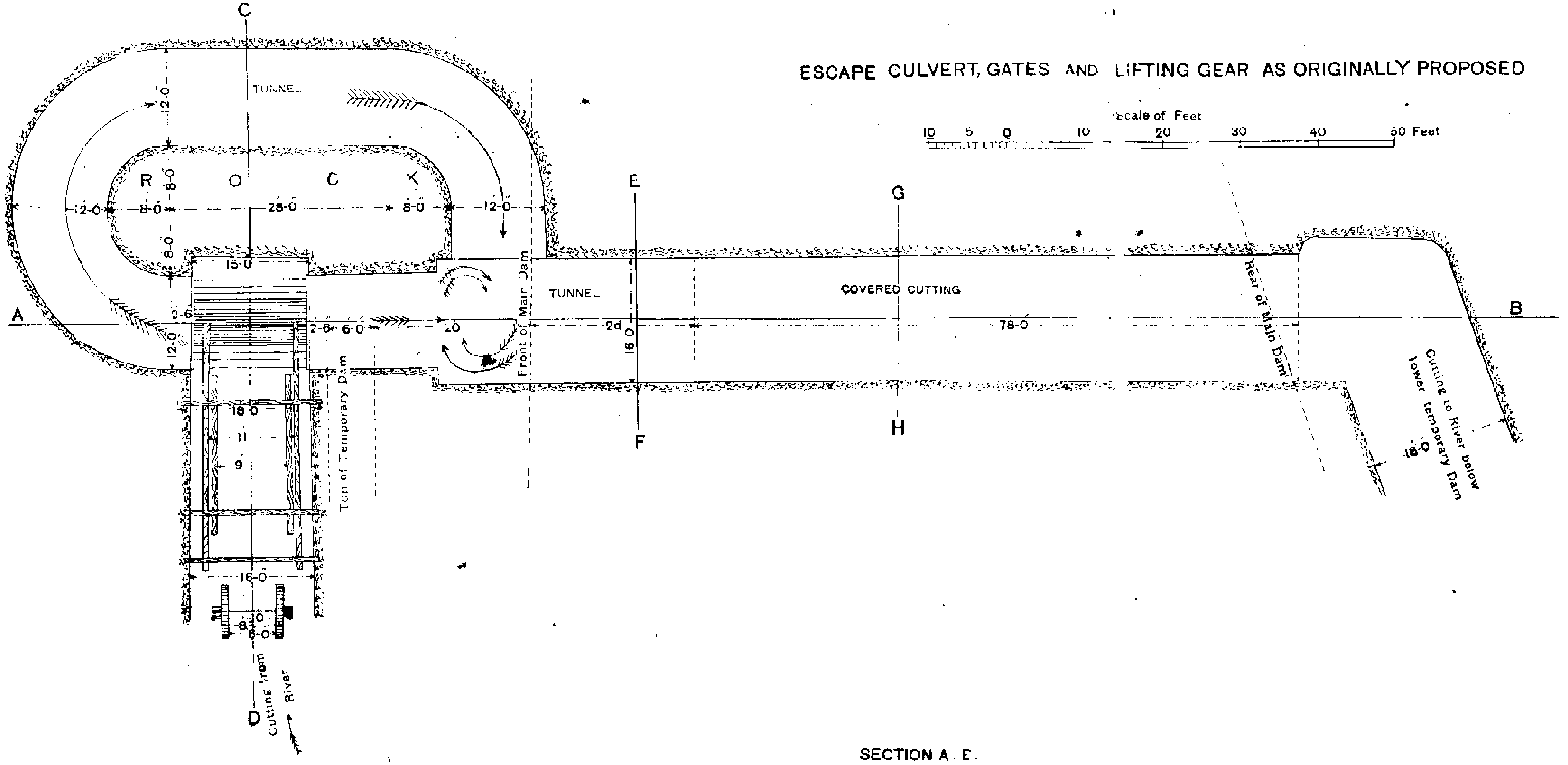
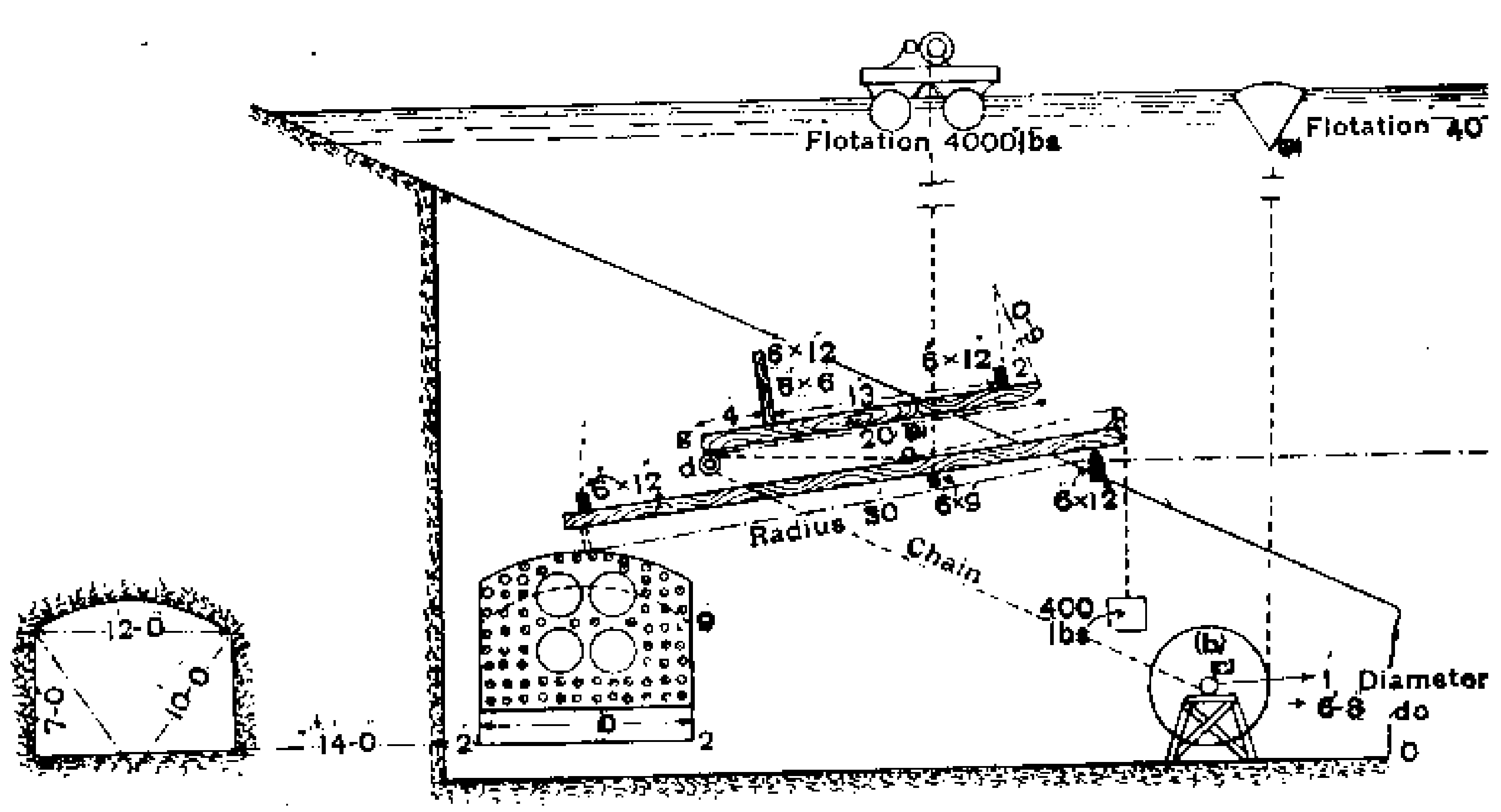
PLATE NO. VI

ESCAPE CULVERT, GATES AND LIFTING GEAR AS ORIGINALLY PROPOSED



SECTION ON C.D



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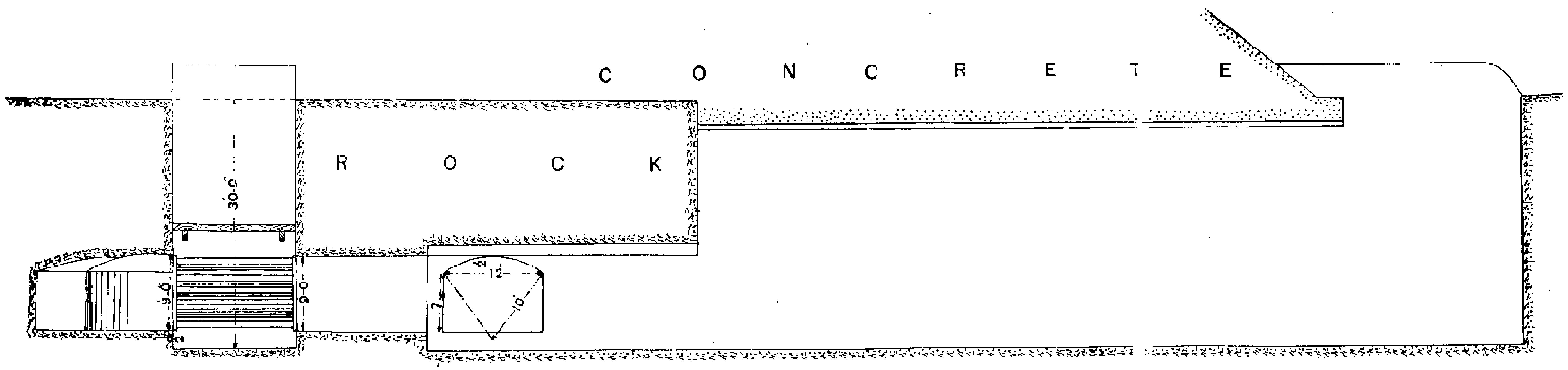
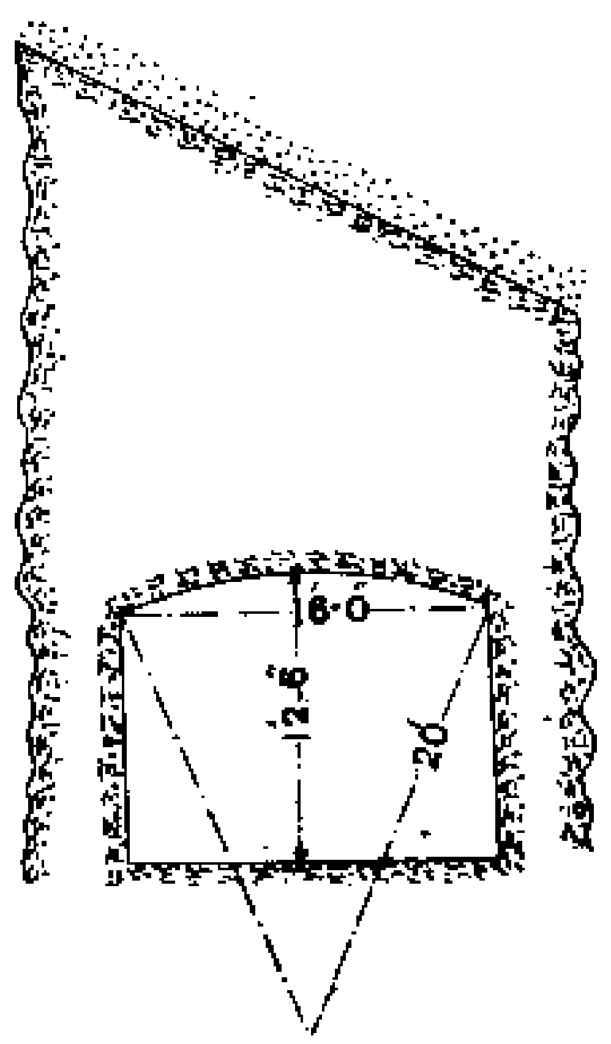


SECTION ON E.F.



SECTION ON G. H.

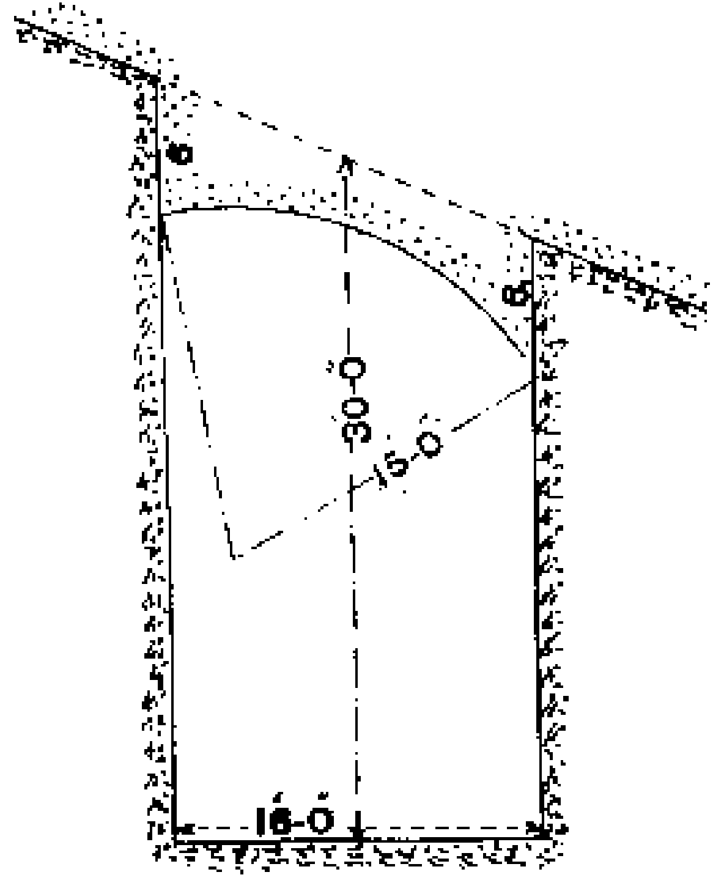


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PLATE NO. VII

LONGITUDINAL SECTION ALONG CREST OF DAM AND ESCAPE

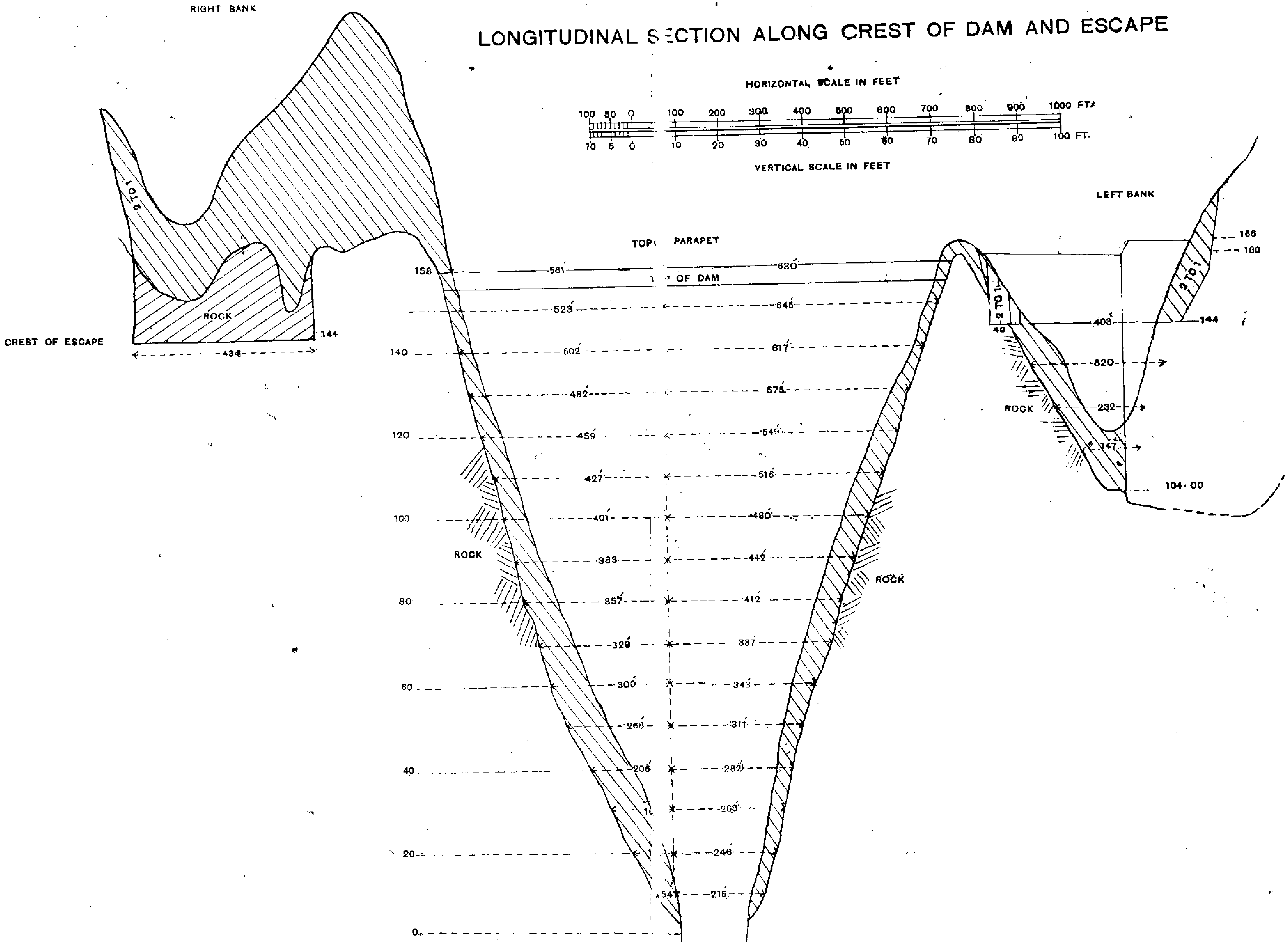
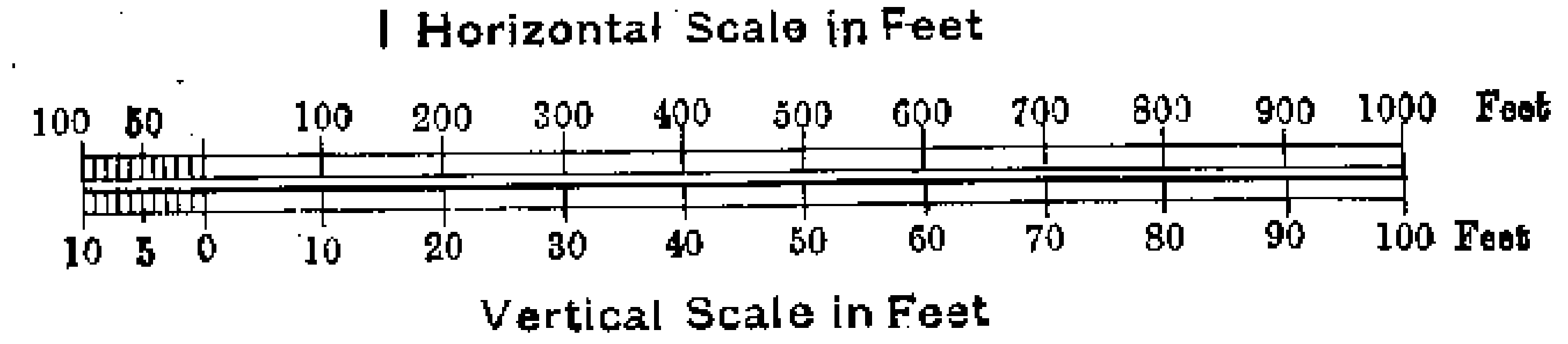


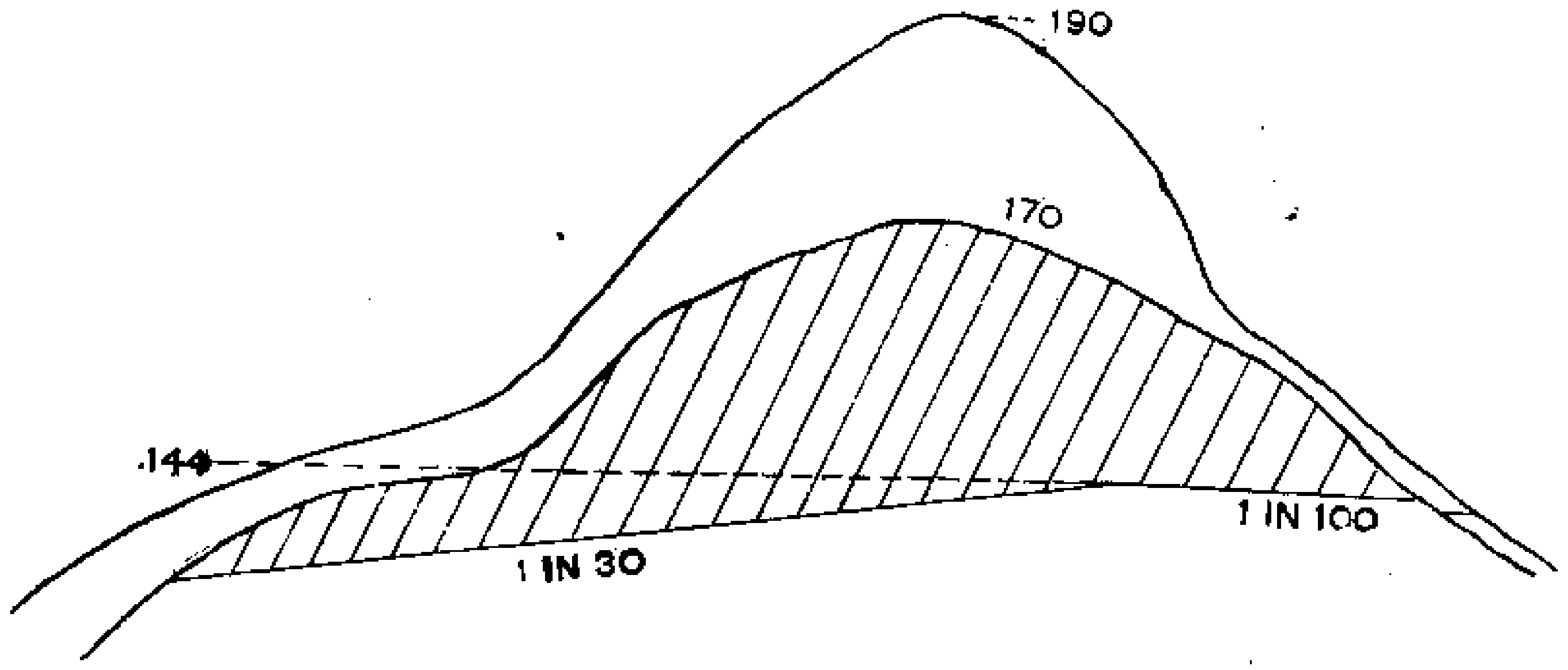
PLATE NO. VIII

PLAN AND SECTION OF RIGHT BANK ESCAPE



| Horizontal Scale in Feet
100 50 0 100 200 300 400 500 600 700 800 900 1000 Feet
10 5 0 10 20 30 40 50 60 70 80 90 100 Feet
Vertical Scale in Feet

SECTION NO. 1



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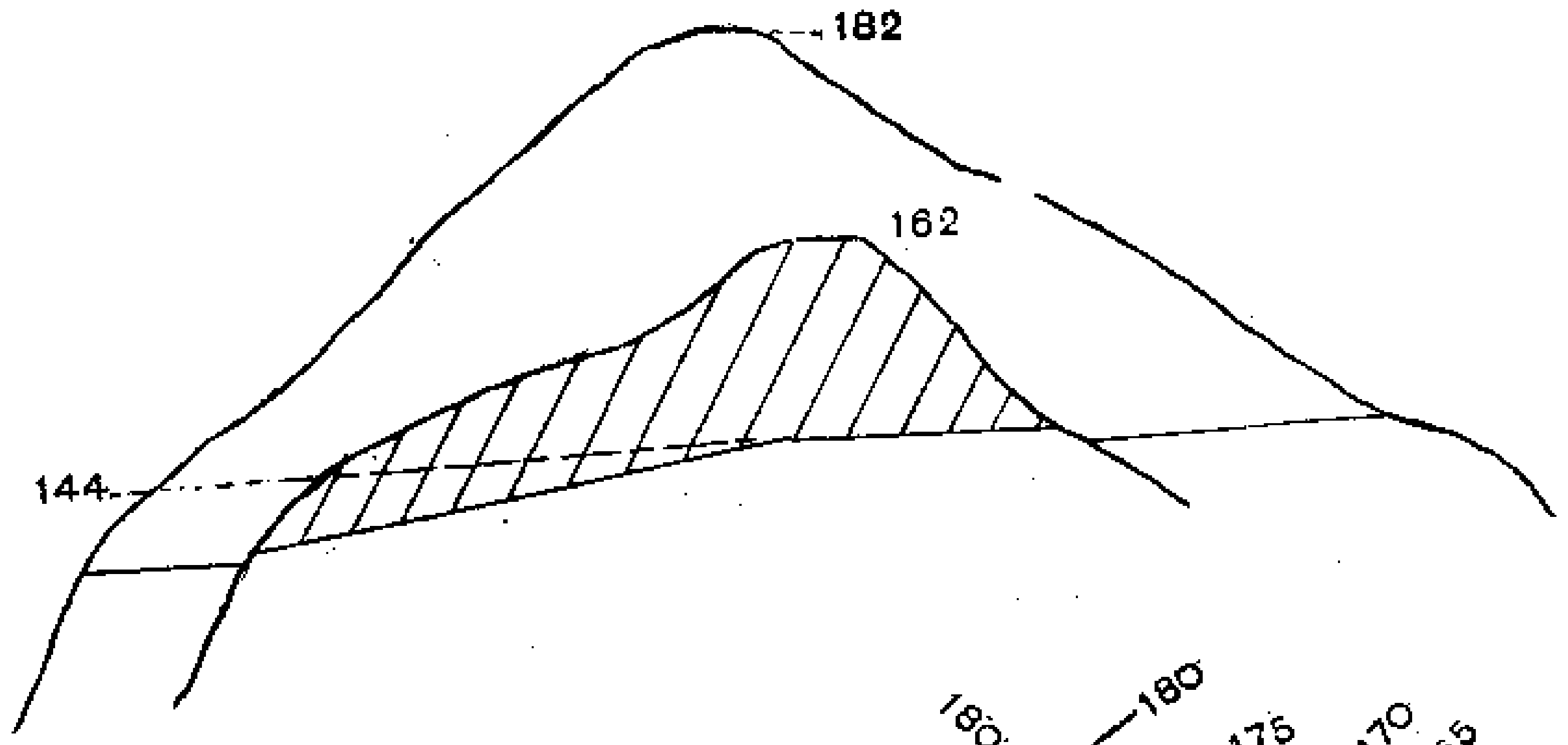

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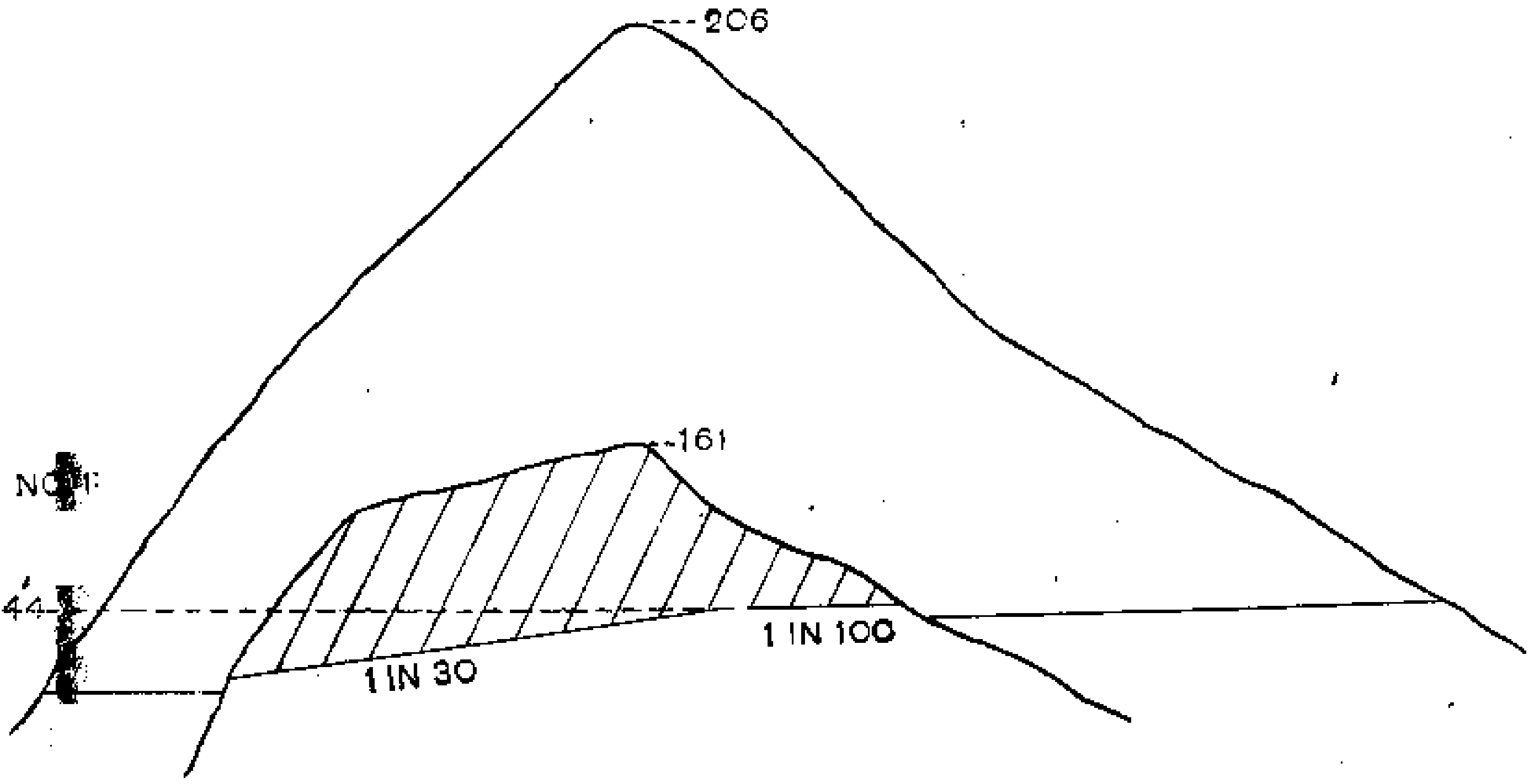

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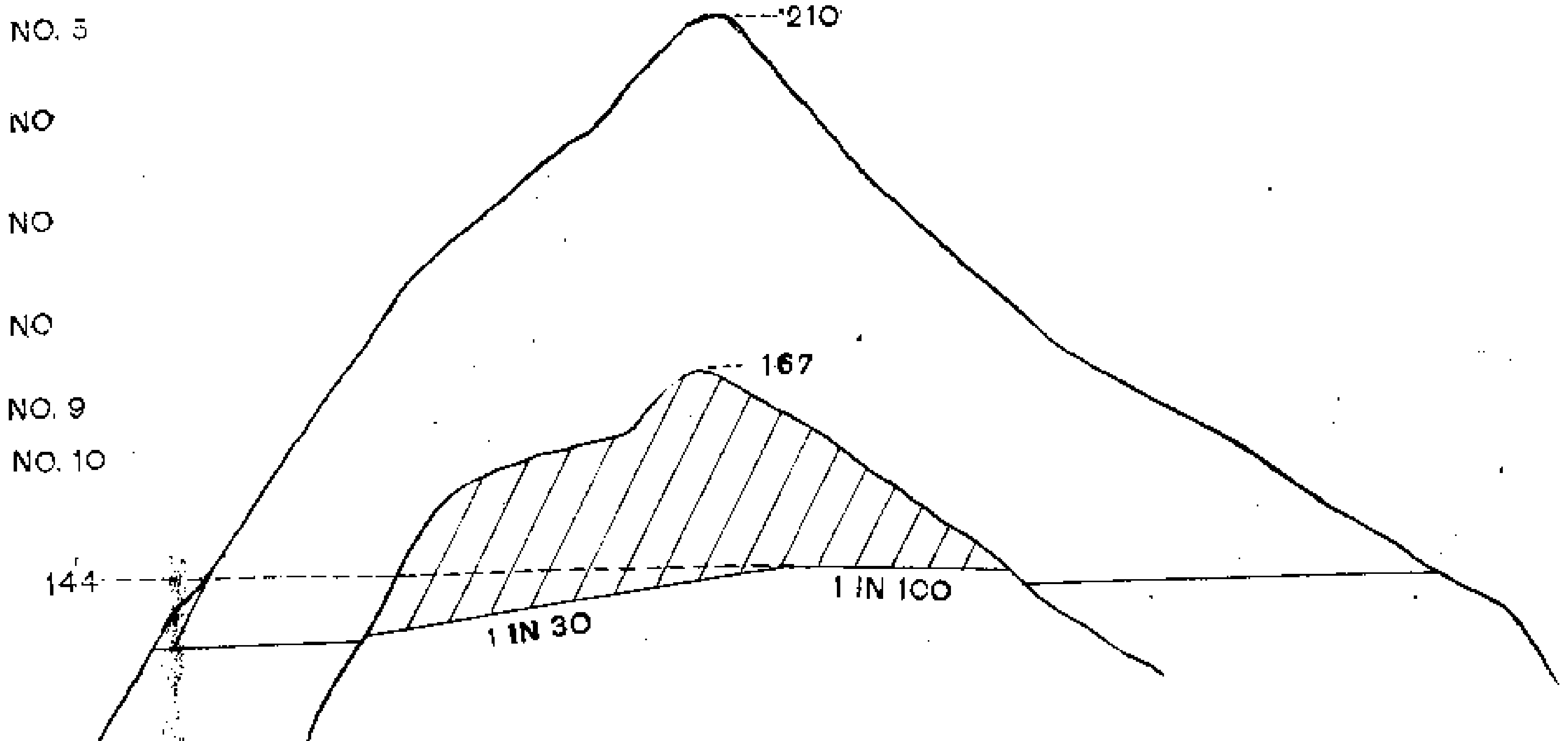

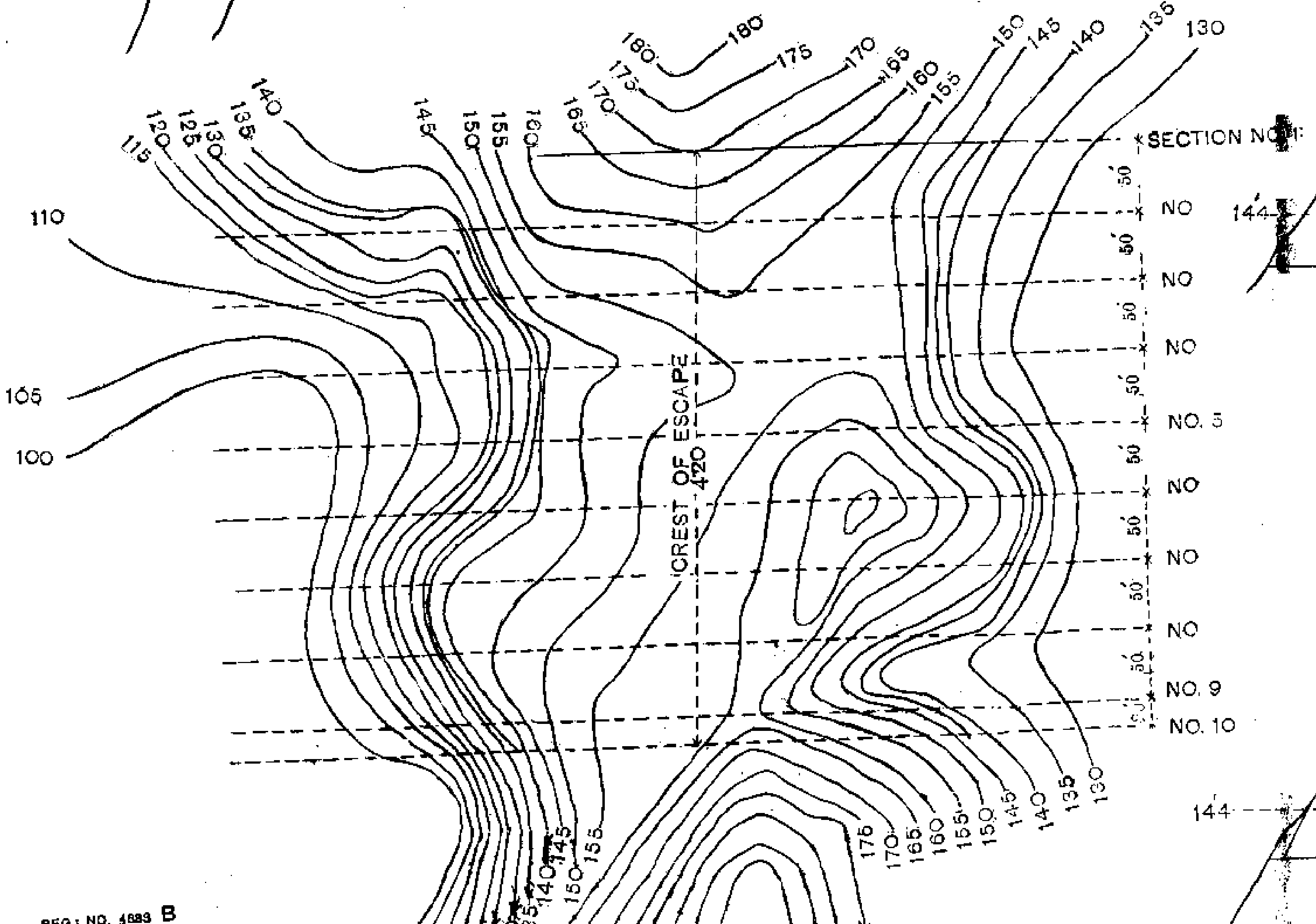

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PERIYAR HEAD SLUICES.

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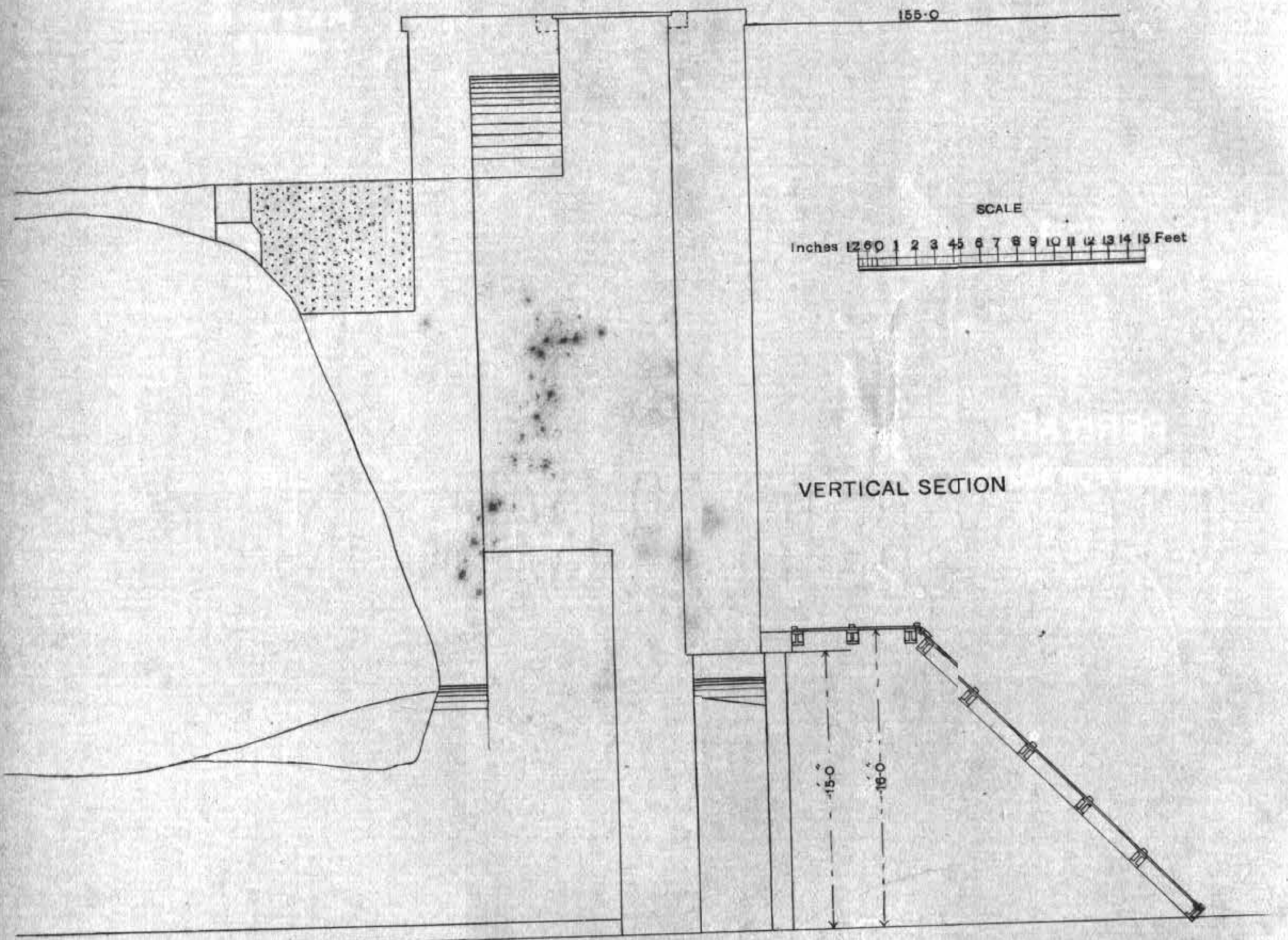
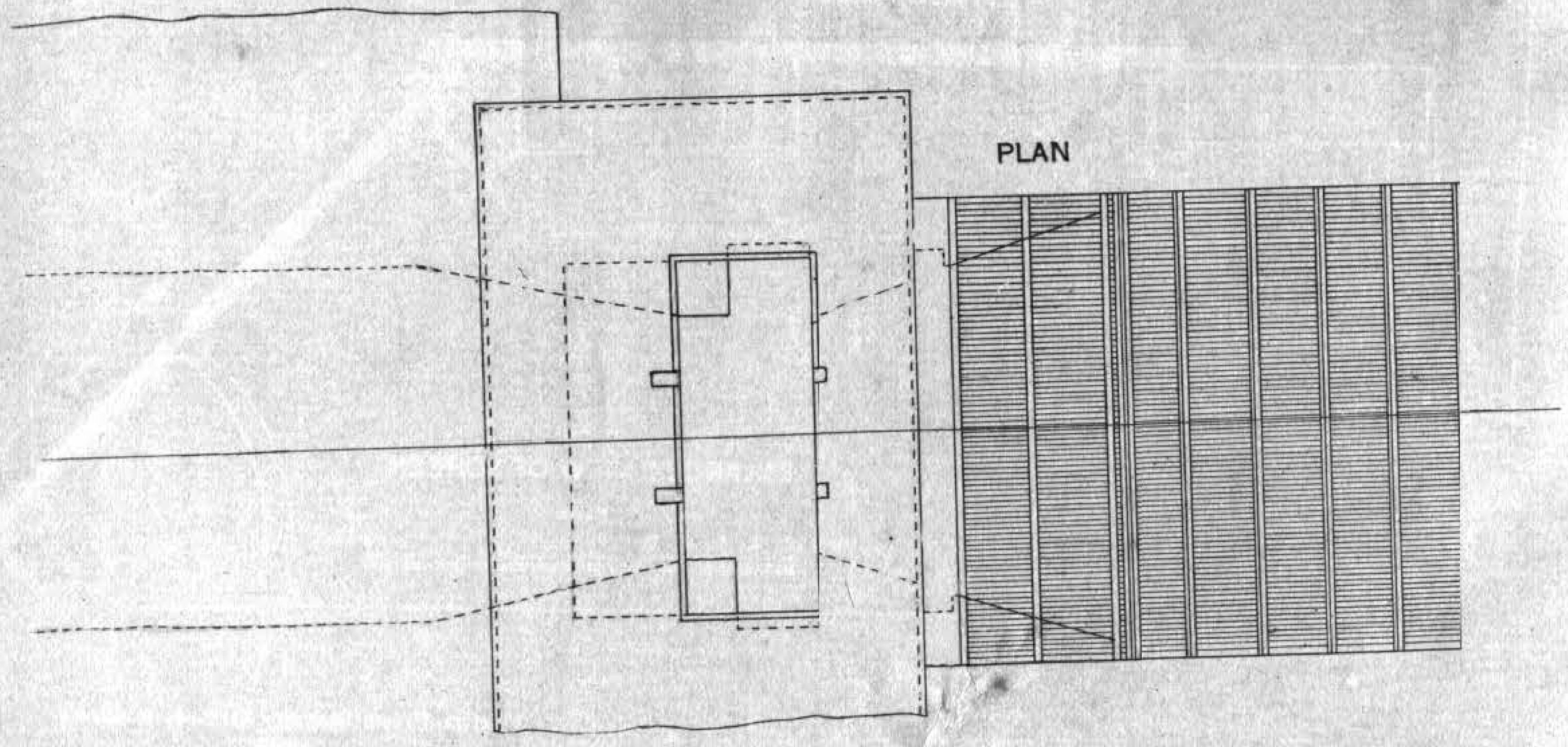
PLATE NO. IX
SHEET II

PERIYAR

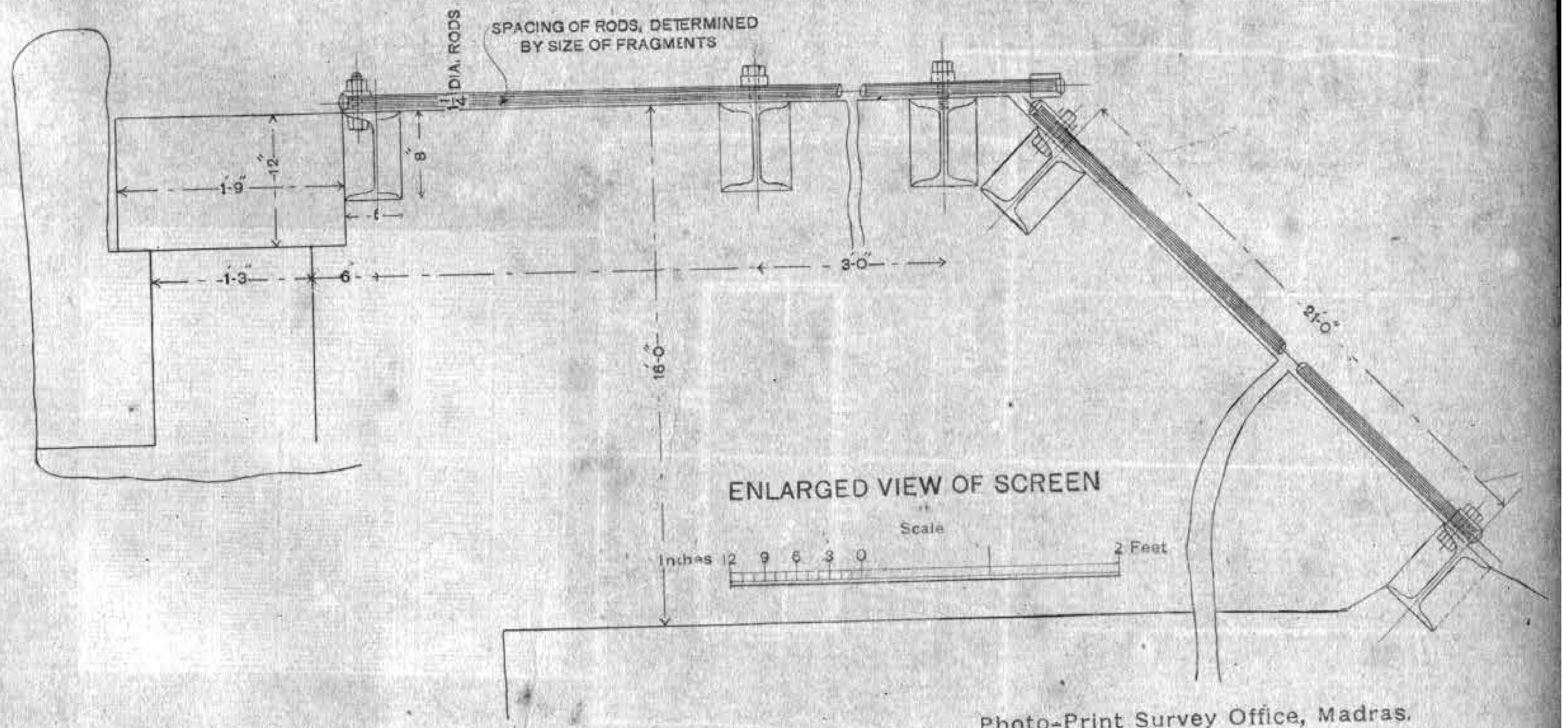
SCREEN FOR SLUICE.



VERTICAL SECTION



PLAN



ENLARGED VIEW OF SCREEN

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PLATE No. IX
SHEET III

PLAN OF PERIYAR HEAD SLUICE

Scale of Feet

N. B.—ALL LEVELS ON THIS PLN HAVE REFERENCE TO THE S.L LEVEL OF 106·75 THAT IS 39·02 FEET BELOW B. M. ON EXISTIG PLATFORM

REFERENCE
- ▭ Rubble in portland Cemen
- ▨ Dressed face stone in Do
- ▩ Archwork cut stone in Do
- ▨ Rubble in surki Mortar
- ▭ Old work
- ▨ Wood work

HALF PLAN AT TOP.
LINE OF EXISTING ROCK A BOTTOM
OLD WORK
MAN HOLE
4-7½
2-6
3-6
4-4½
6-0
4-1½
6-9
16-0
11-6
9-6
17-8
A
B
C
8-10
10-0
8-6
7-6
4-9
2-9
2-3
6-9
9-0
11-6
2-6
6-0
5-0
LINE OF EXISTING ROCK AT BOTTOM
OLD WORK
NEW WORK HERE TO BE BONDED INTO EXISTING MASONRY AND ROCK
HALF PLAN AT BOTTOM
IN SURKI MORTR
THE DIMENSIONS OF THIS RECESS HERE GIVEN ARE APPROXIMTE THE MASONRY MUST BE MADE TO SIT THE IRON WORK
SECTION ON A. A
RAILING TO BE 9" FROM EDGE
2" PLANK
+156·25
JOIST 7"×3½"
10·48
B.M. ON TOP OF EXISTING PLATFORM +145·77
3-0
VERTICAL IRON LADDER FIXED TO MASONRY
12-3
FULL LKE LEVEL +144·00
CHANNEL IRON BEAMS EMBEDDED SUPPORT SCREW SHAFT
15-6
6-0
17-0
49-6
D
+127·00 BELOW THIS PORTLAD CEMENT MASONRY
12-0
BEAM TO COVER OPENING LEFT FOR INSERTION OF TEMPORARY SHUTER WHEN REQUIRED
+122·00
+119·50
12-9
15-3
SILL LEVEL +106·75
HALF SECTION ON D. D.
NEW WORK HERE TO BE BONDED IN TO EXISTING MASONRY AND AT BACK TO BE CARRIED TO ROCK
5-0
2-3
15-6
6-0
6-9
16-0
SECTIONAL ELEVATION ON B. B. B. B.
11-0
+156·25
3-6
+127·00
BELOW THIS PORTLAND CEMENT MASORY
2-3
5-3
LINE OF ROCK
+122·00
20-3
12-9
4-9
GROOVE FOR TEMPORARY SHUTTER
ROCK TO BE BENCHED AS HERE SHOWN WHERE EVER MASONRY RESTS ON IT
+106·75
6-0
2-3
13-6
27-0
SECTION ON C.C.
2-6
+122·00
IN SURKI MORTAR
5-0
+106·75
10
5
0
10
20 FEET

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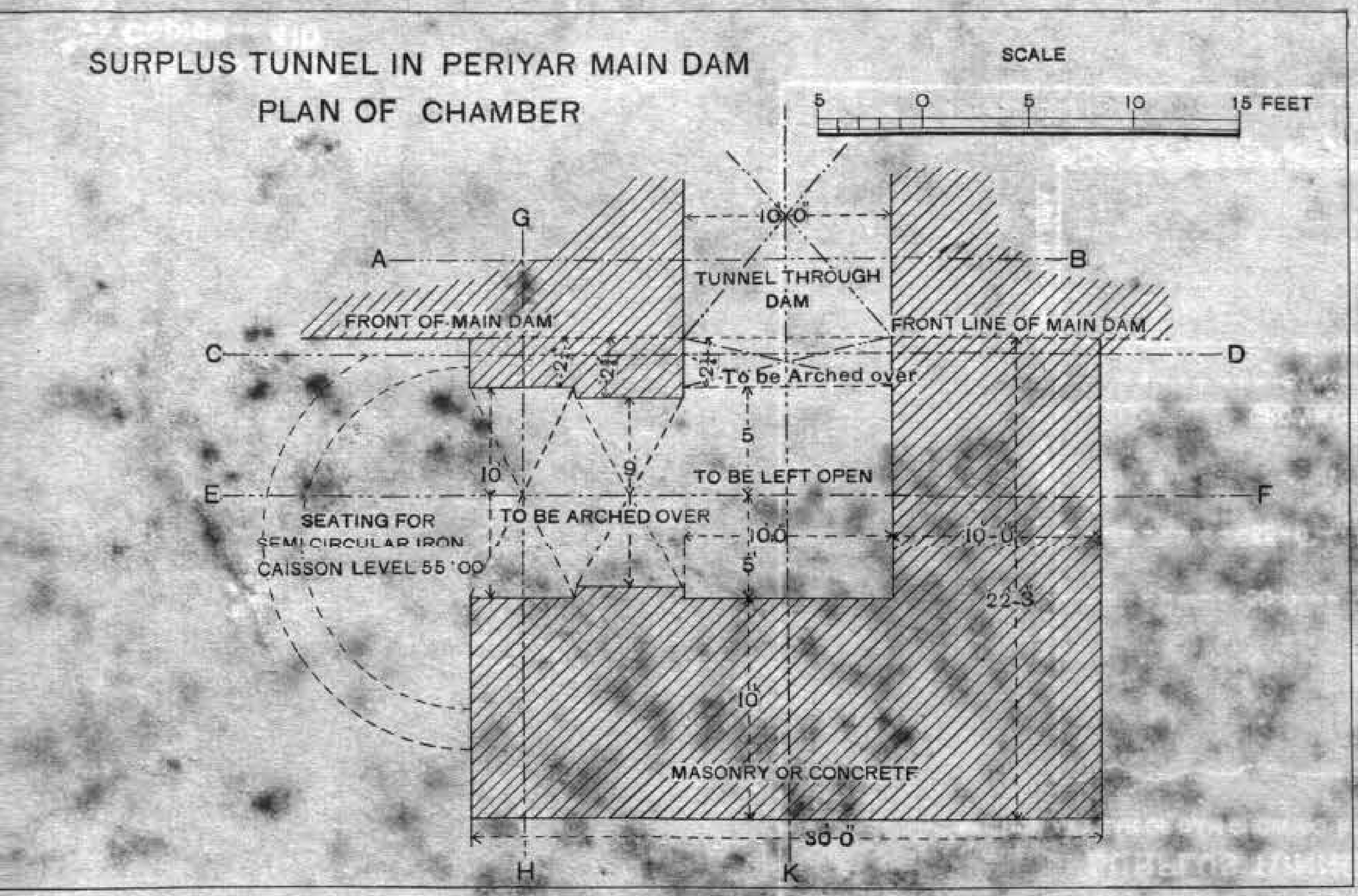
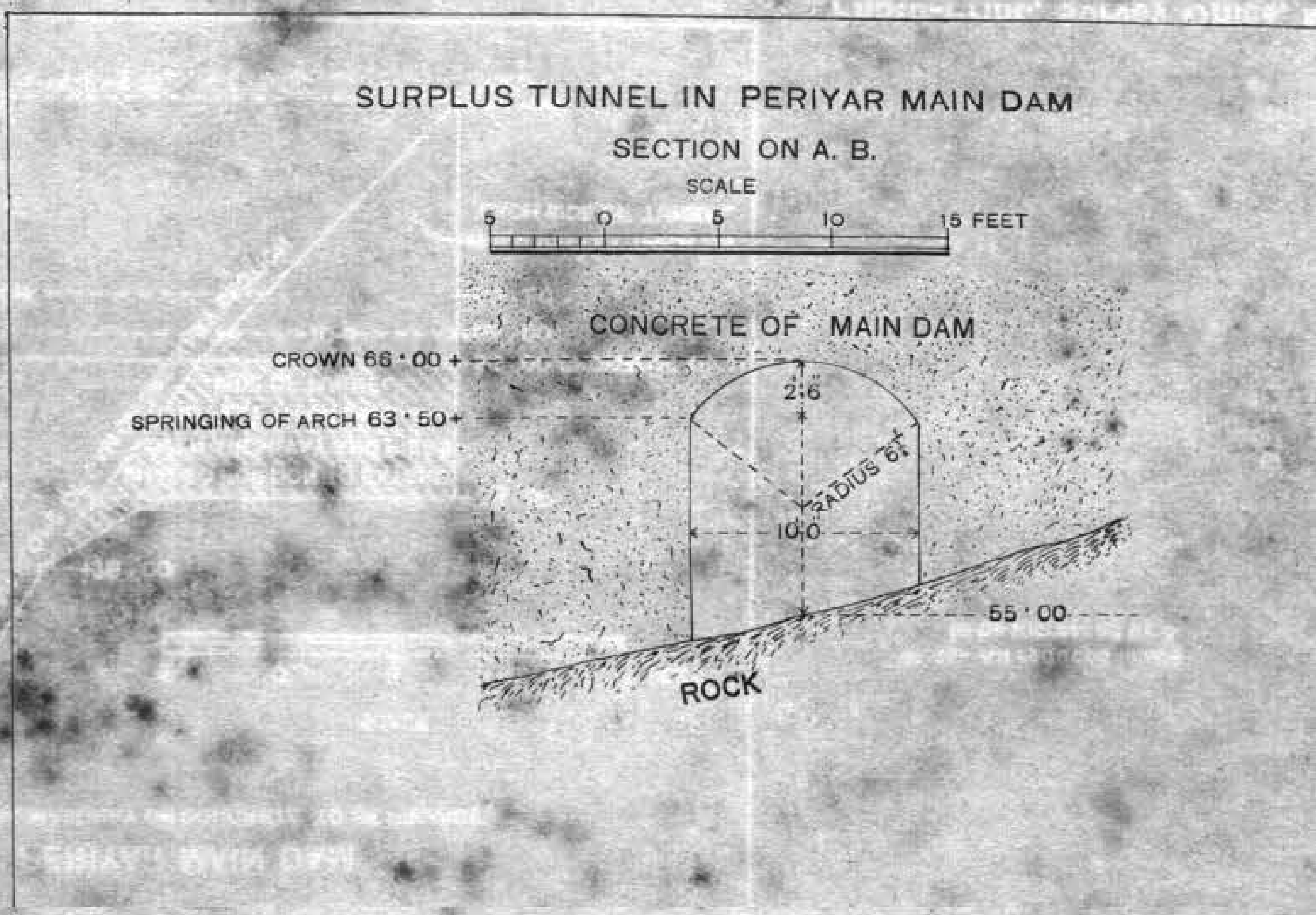


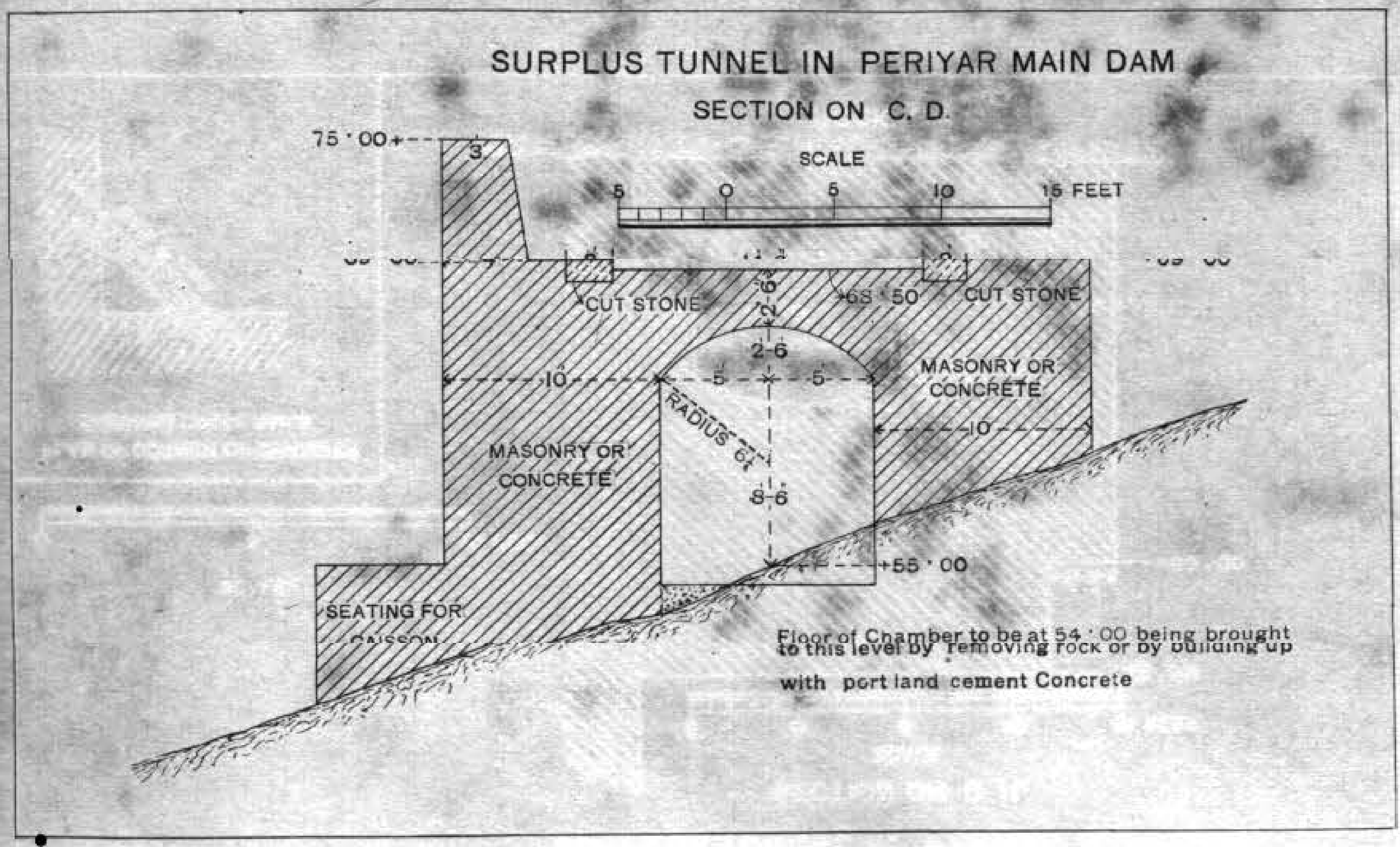
SURPLUS TUNNEL IN PERIYAR MAIN DAM

PLAN OF CHAMBER



SURPLUS TUNNEL IN PERIYAR MAIN DAM

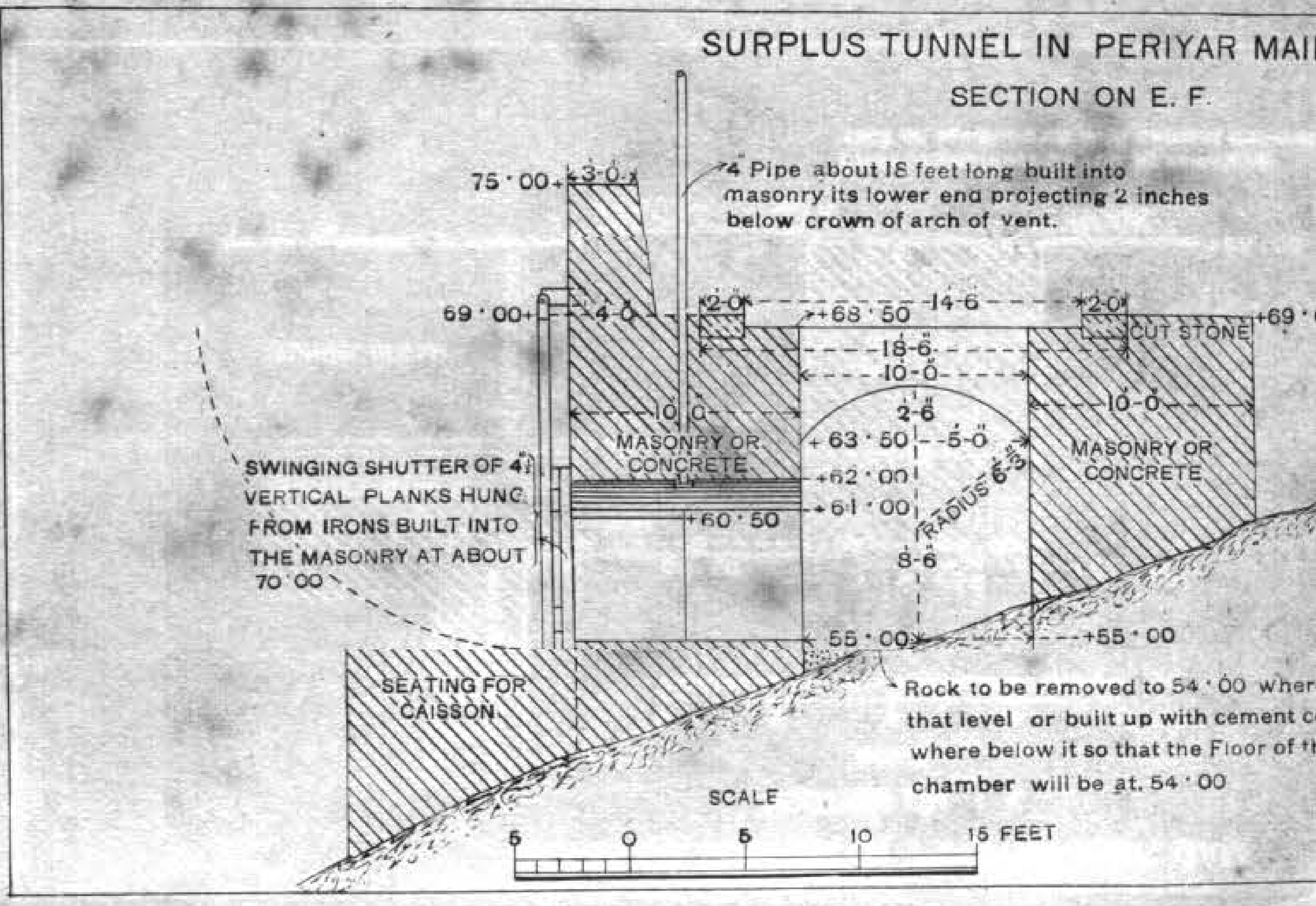
SECTION ON A. B.



SURPLUS TUNNEL IN PERIYAR MAIN DAM

SECTION ON C. D.

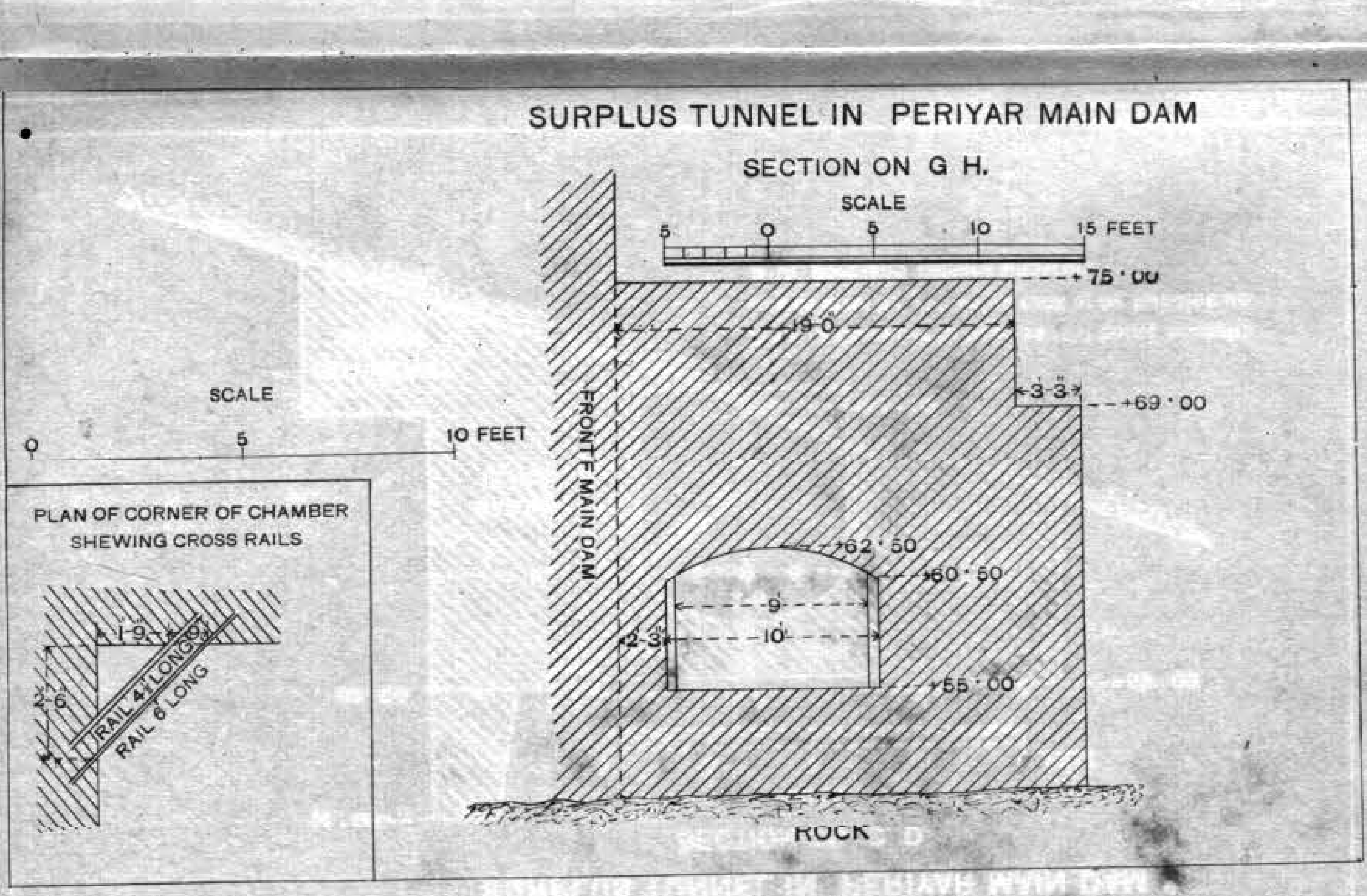
Floor of Chamber to be at 54·00 being brought to this level by removing rock or by building up with port land cement Concrete



SURPLUS TUNNEL IN PERIYAR MAI

SECTION ON E. F.

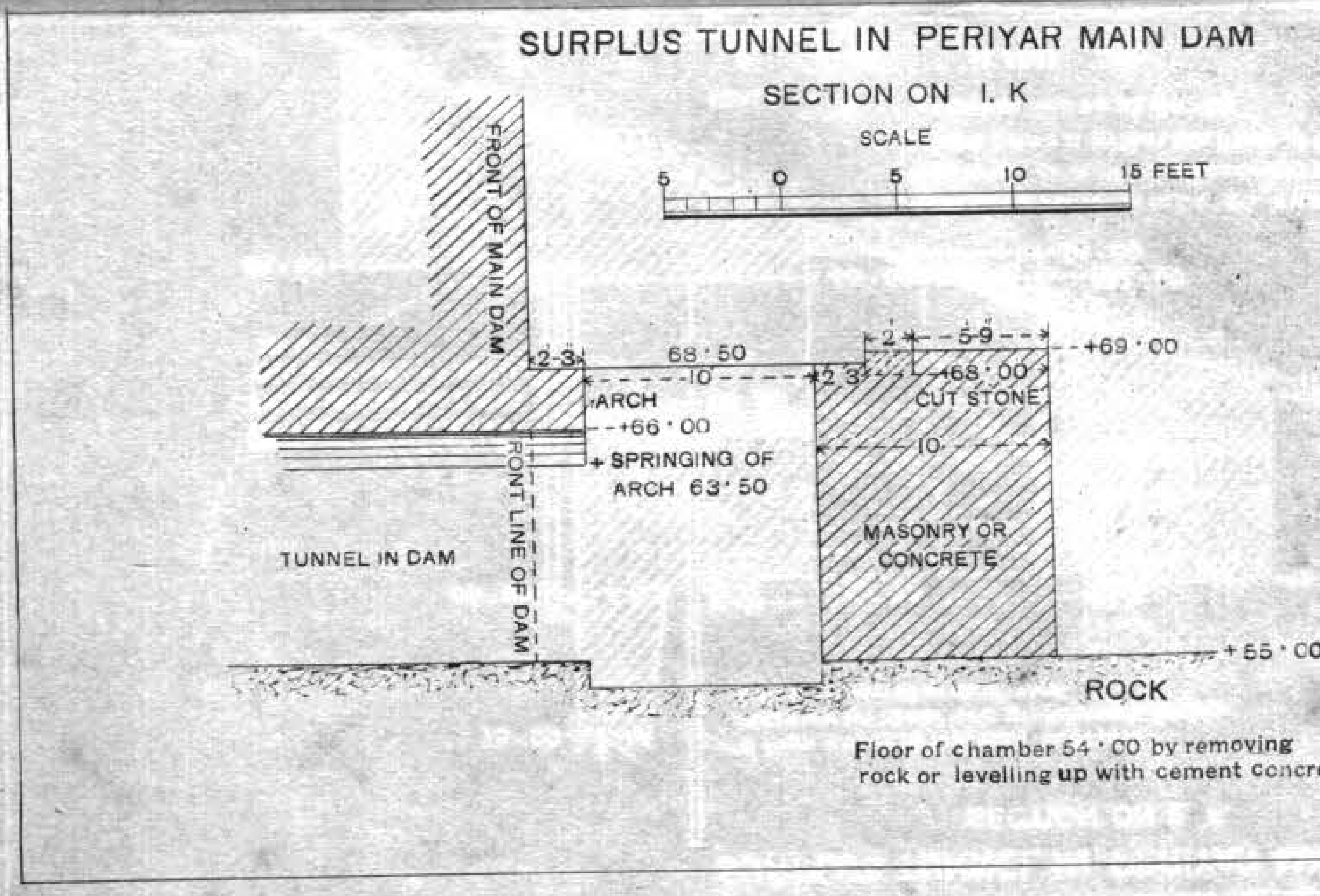
75·00
3-0
4" Pipe about 18 feet long built into masonry its lower end projecting 2 inches below crown of arch of vent.
69·00
4-0
2-0
+68·50
14-6
2-0
+69·
CUT STONE
18-6
10-0
10-0
2-6
10-0
MASONRY OR CONCRETE
+63·50
5-0
+62·00
+61·00
+60·50
RADIUS 6'
MASONRY OR CONCRETE
8-6
SWINGING SHUTTER OF 4" VERTICAL PLANKS HUNG FROM IRONS BUILT INTO THE MASONRY AT ABOUT 70·00
SEATING FOR CAISSON
55·00
+55·00
Rock to be removed to 54·00 wher that level or built up with cement c where below it so that the Floor of th chamber will be at 54·00
SCALE
5 0 5 10 15 FEET



SURPLUS TUNNEL IN PERIYAR MAIN DAM

SECTION ON G H.

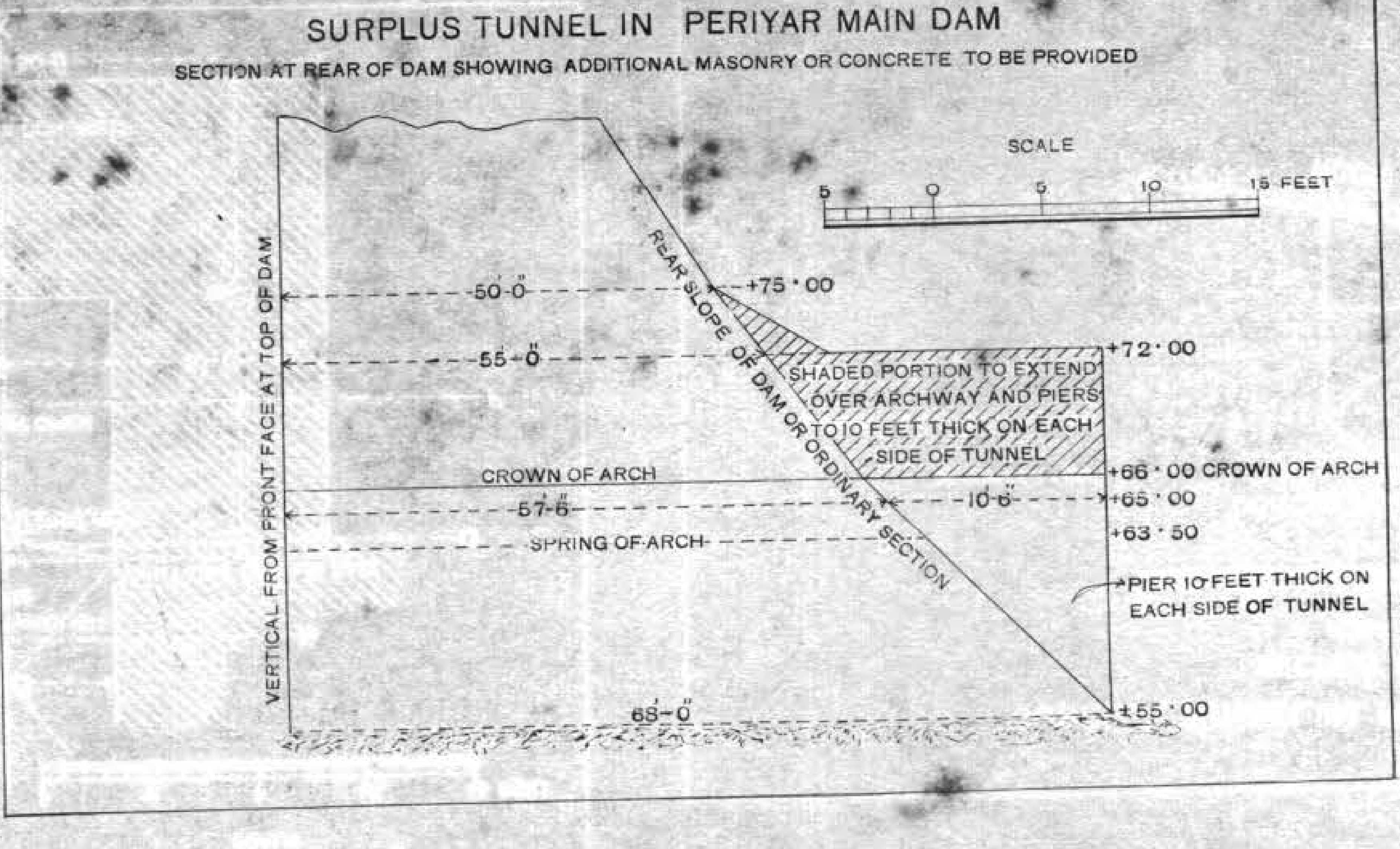
PLAN OF CORNER OF CHAMBER SHEWING CROSS RAILS



SURPLUS TUNNEL IN PERIYAR MAIN DAM

SECTION ON I. K

Floor of chamber 54·00 by removing rock or levelling up with cement concr



SURPLUS TUNNEL IN PERIYAR MAIN DAM

SECTION AT REAR OF DAM SHOWING ADDITIONAL MASONRY OR CONCRETE TO BE PROVIDED

SCALE
5 0 5 10 15 FEET
VERTICAL FROM FRONT FACE AT TOP OF DAM
50-0
+75·00
55-0
REAR SLOPE OF DAM OR ORDINARY SECTION
+72·00
SHADED PORTION TO EXTEND OVER ARCHWAY AND PIERS TO 10 FEET THICK ON EACH SIDE OF TUNNEL
CROWN OF ARCH
+66·00 CROWN OF ARCH
57-6
10-6
+65·00
+63·50
SPRING OF ARCH
PIER 10 FEET THICK ON EACH SIDE OF TUNNEL
68-0
+55·00

Note- All reduced levels to be increased by 6.

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PLATE X
SHEET 2

DETAILSOF SURPLUS TUNNEL SLUICE

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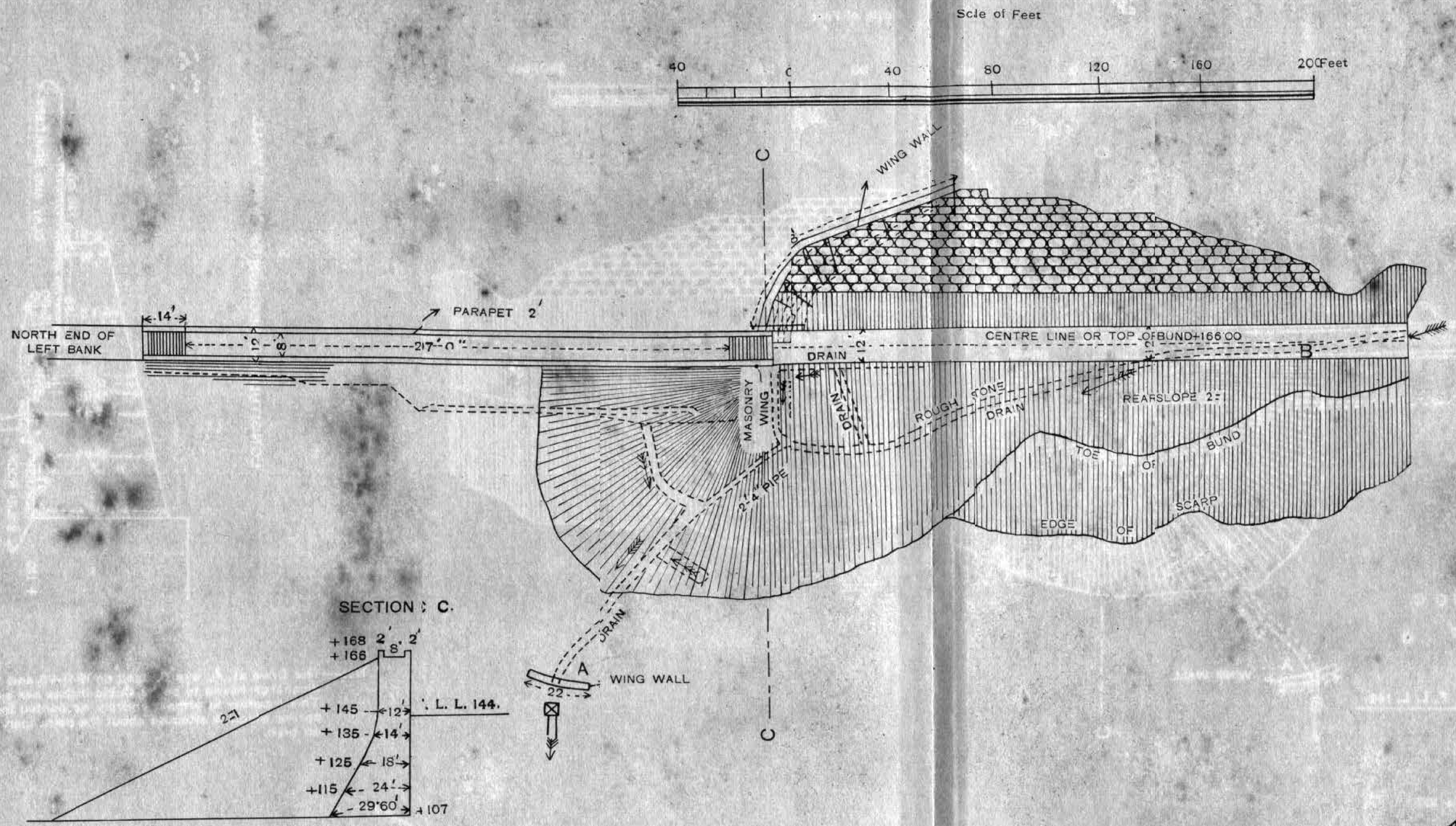
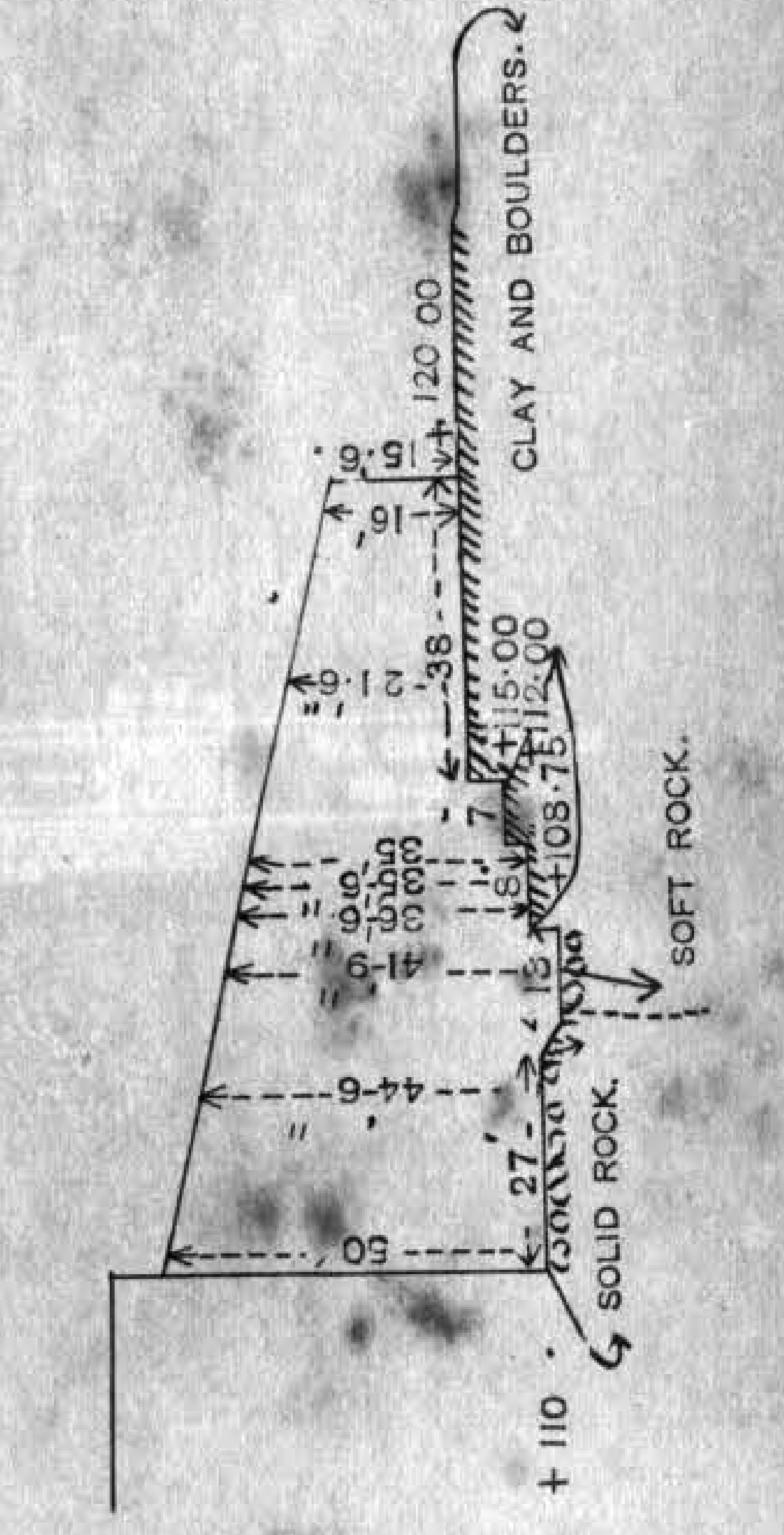
PLAN OF LEFTBANK EXTENSION

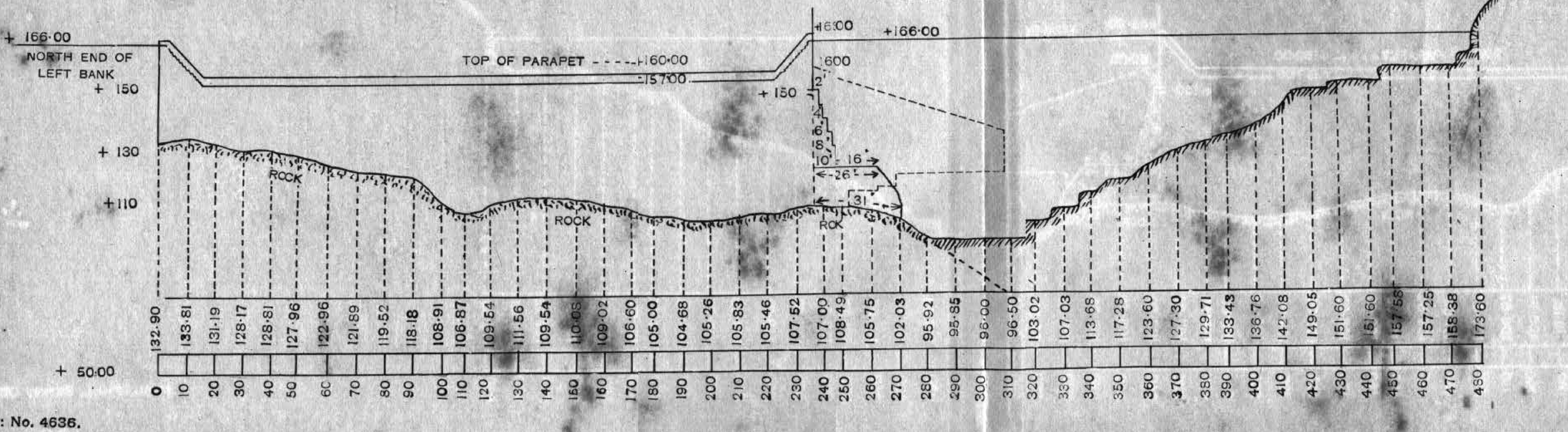


LONGITUDINAL SECTION OF WING WALL.



Note—The Drain at, A, was Gauged on 19-11-95, and the discharge found to be 32 Cubic inches per second. This quantity is almost entirely accounted for by a spring which is situated about the point marked, B, on plan.

LONGITUDINAL SECTION OF LIFT BANK.



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LONGTUDINAL SECTION OF PERIYAR MAIN CHANNEL

TYPCAL SECTIONS OF PIRIYAR MAIN CHANNIL

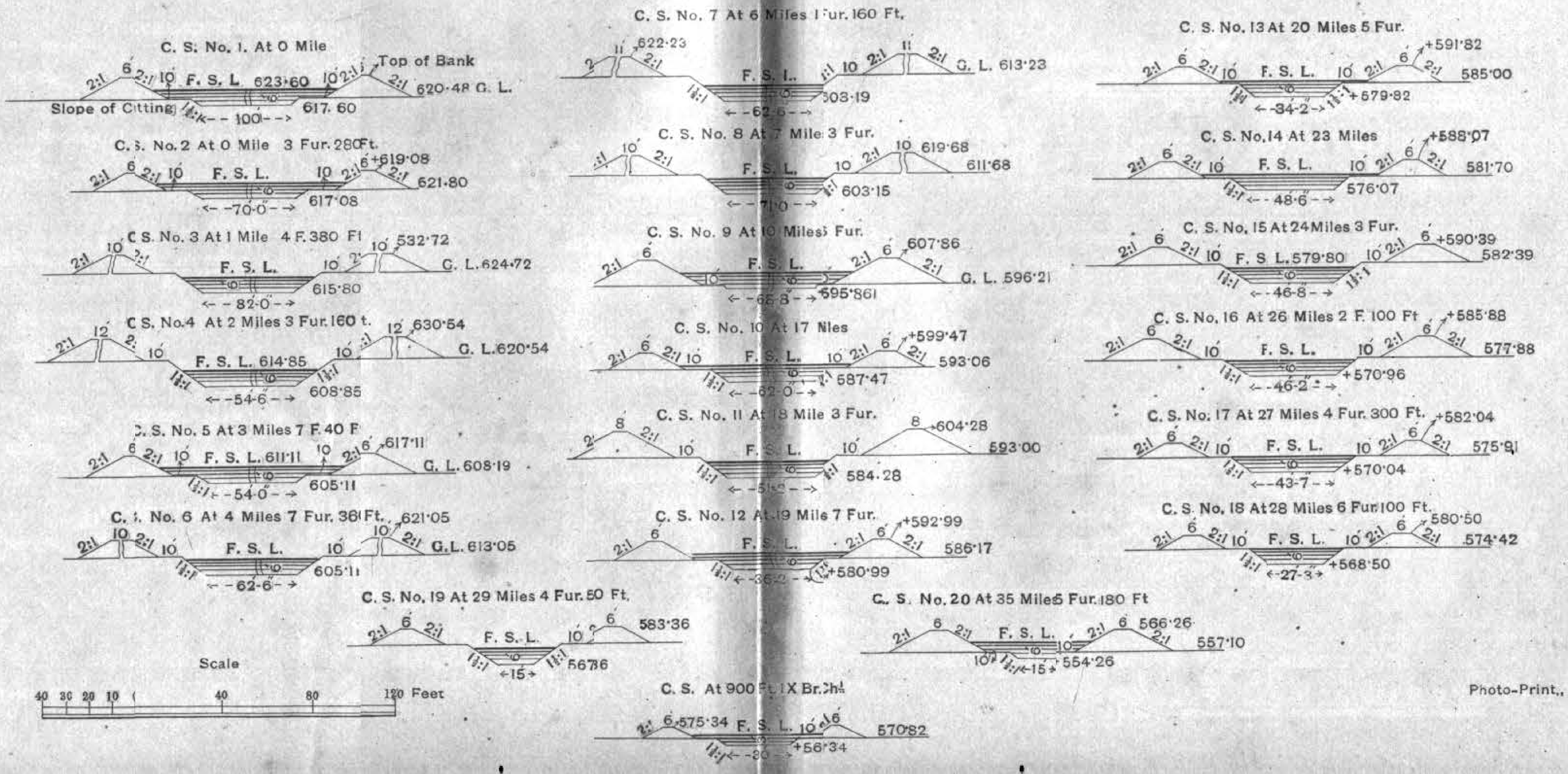

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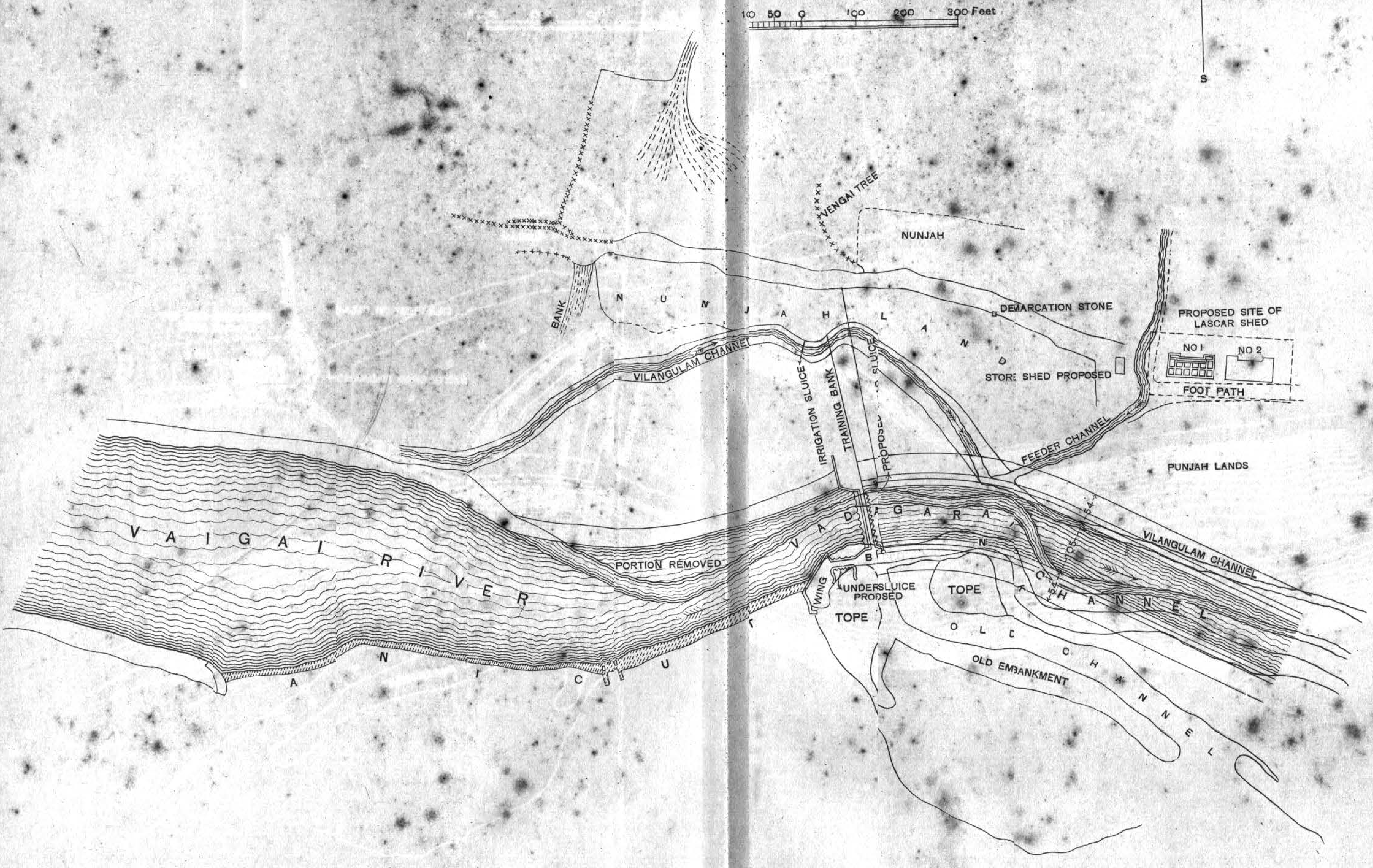
PLATE No. XIII

SURVEY OF ANICUT
PERANA



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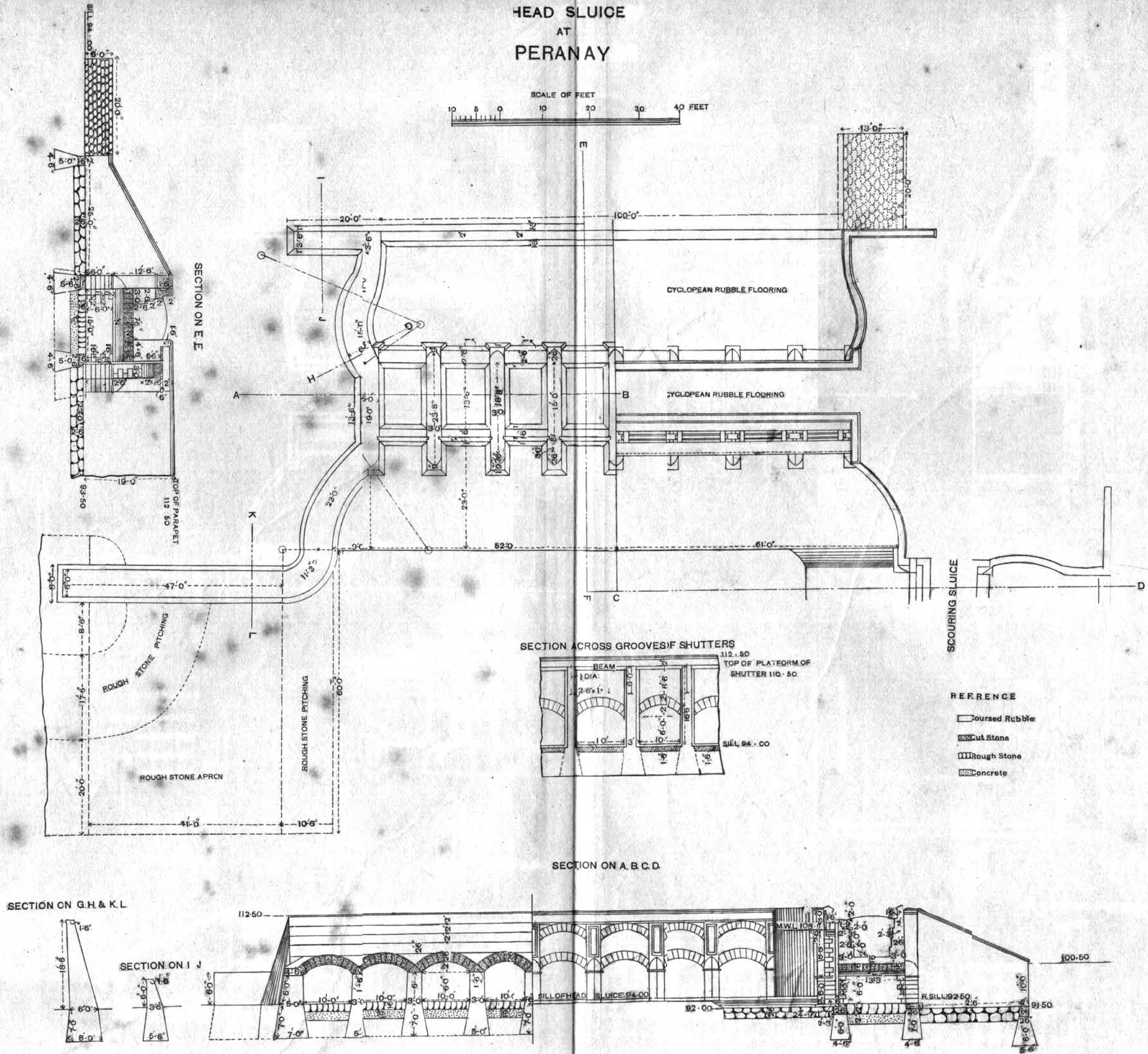
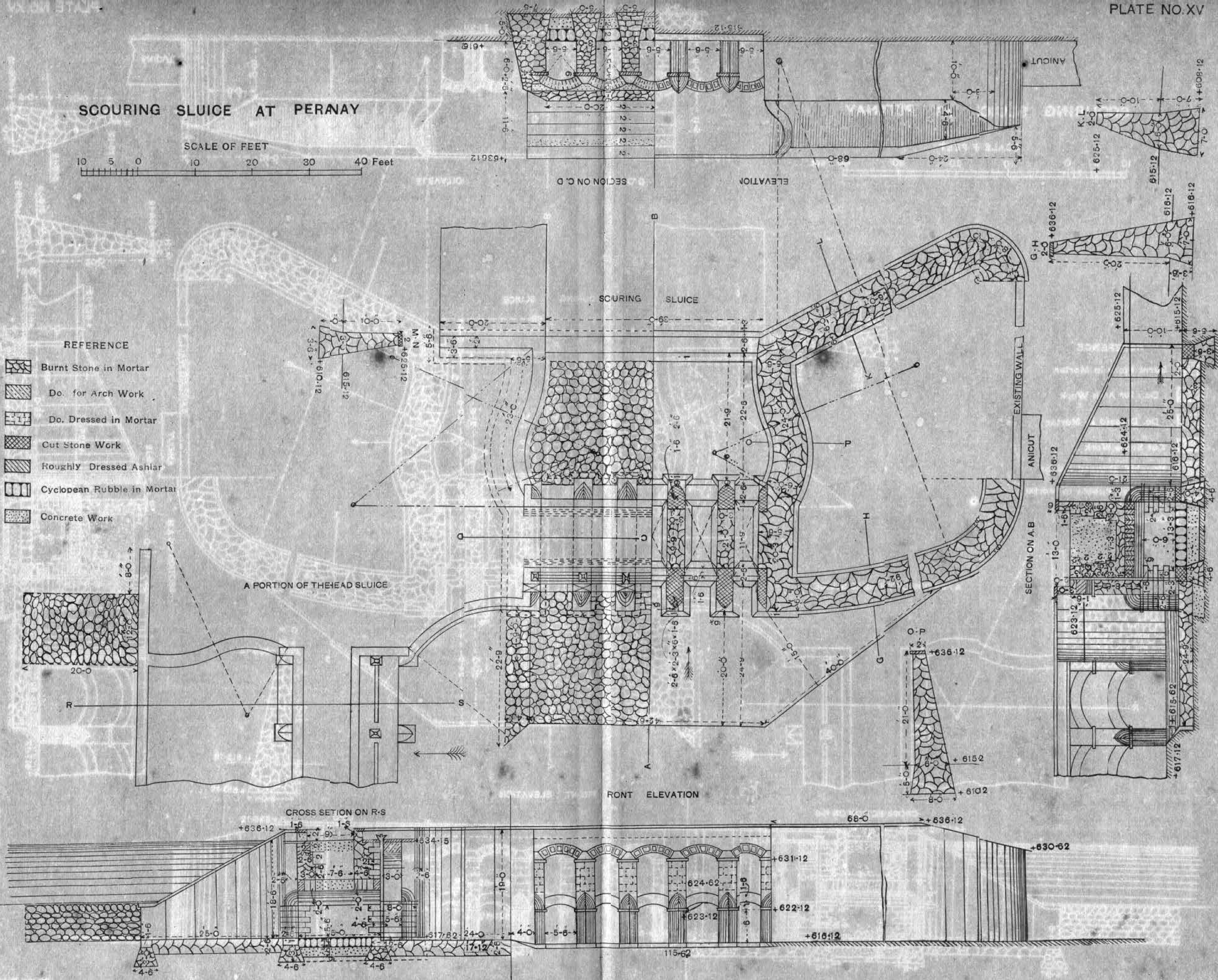
PLAN
OF
HEAD SLUICE
AT
PERANAY



SCOURING SLUICE AT PERANAY



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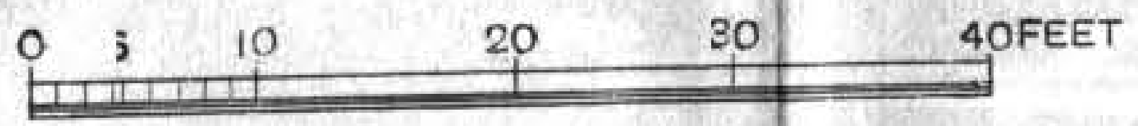
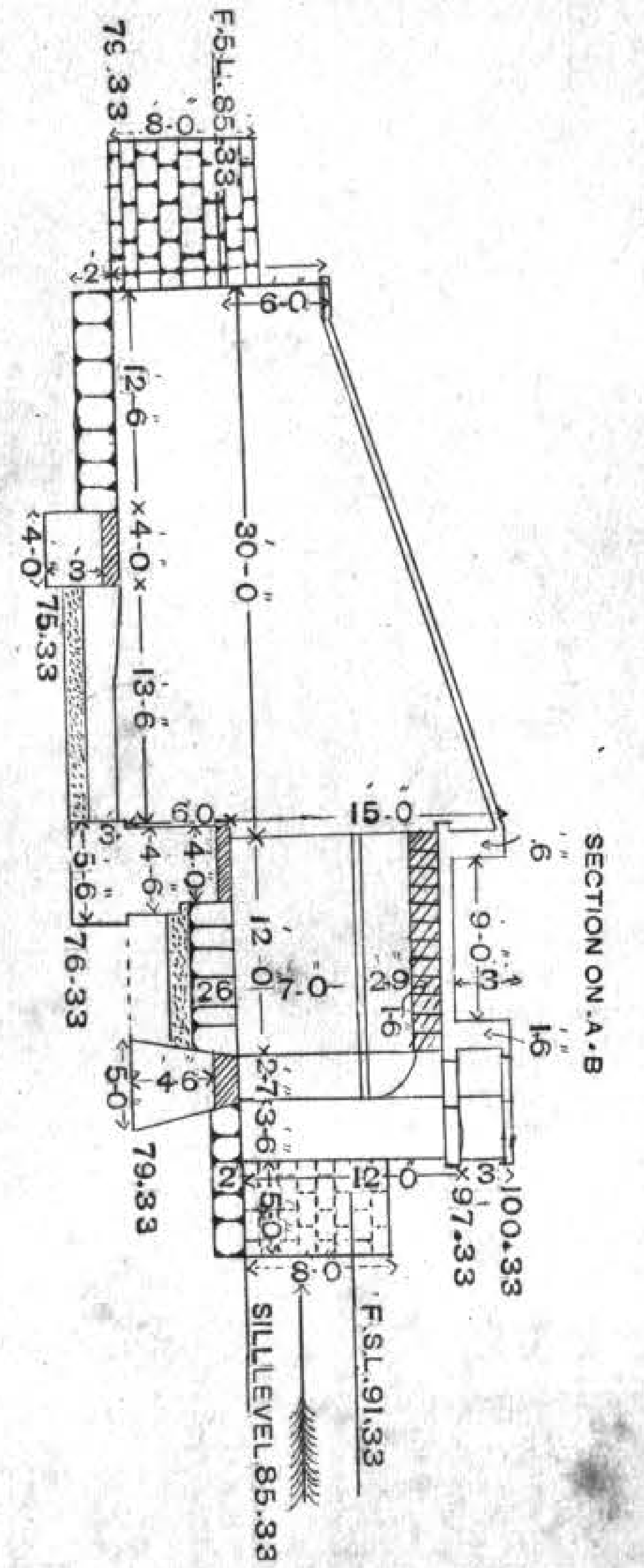
PLAN
OF
FALL AND BRIGE
COMBINED
T 2¼ MILES FIRST REACH MAI CHANNEL

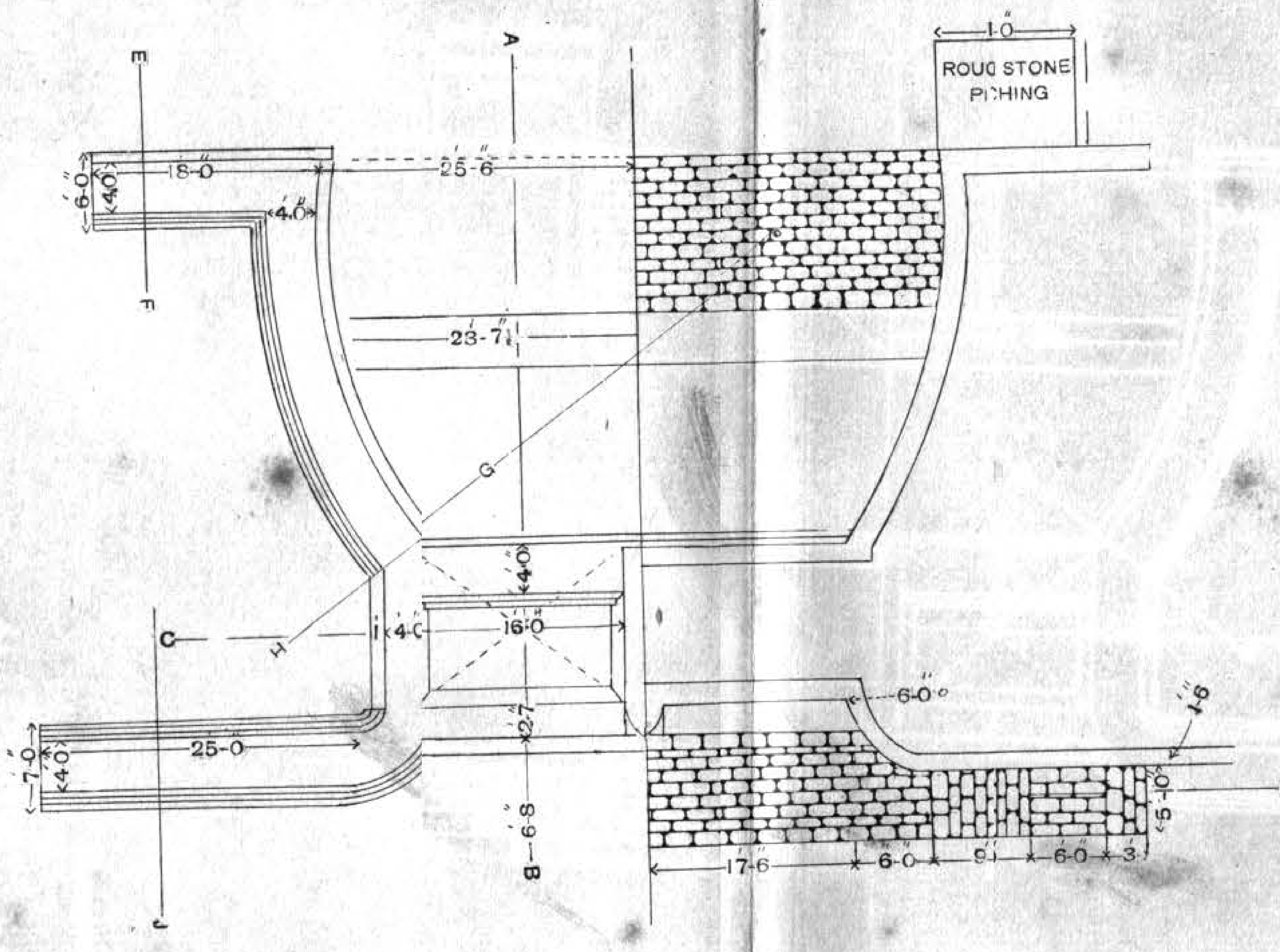
PLATE NO. XVI

SCALE

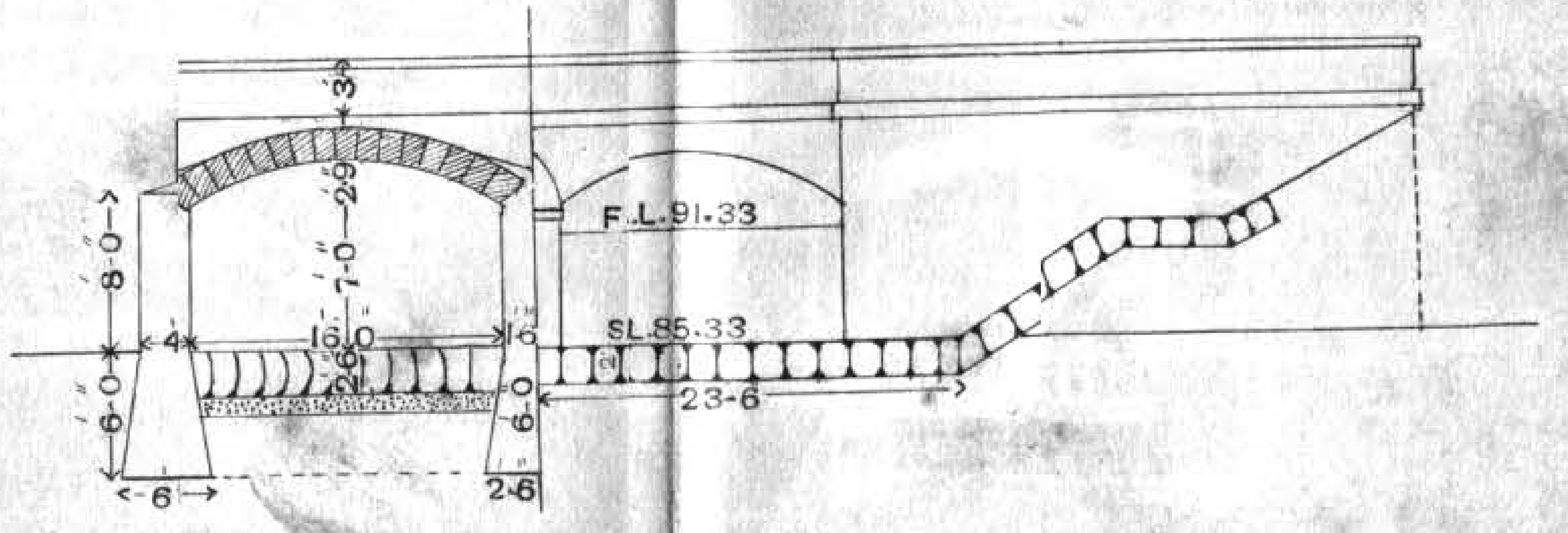




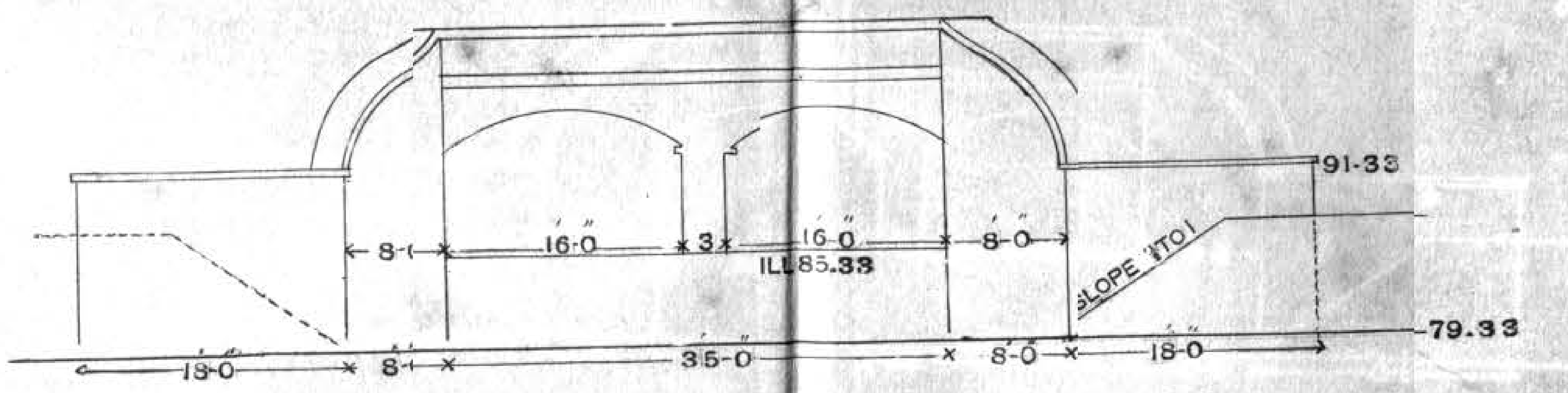
SECTION ON A-B



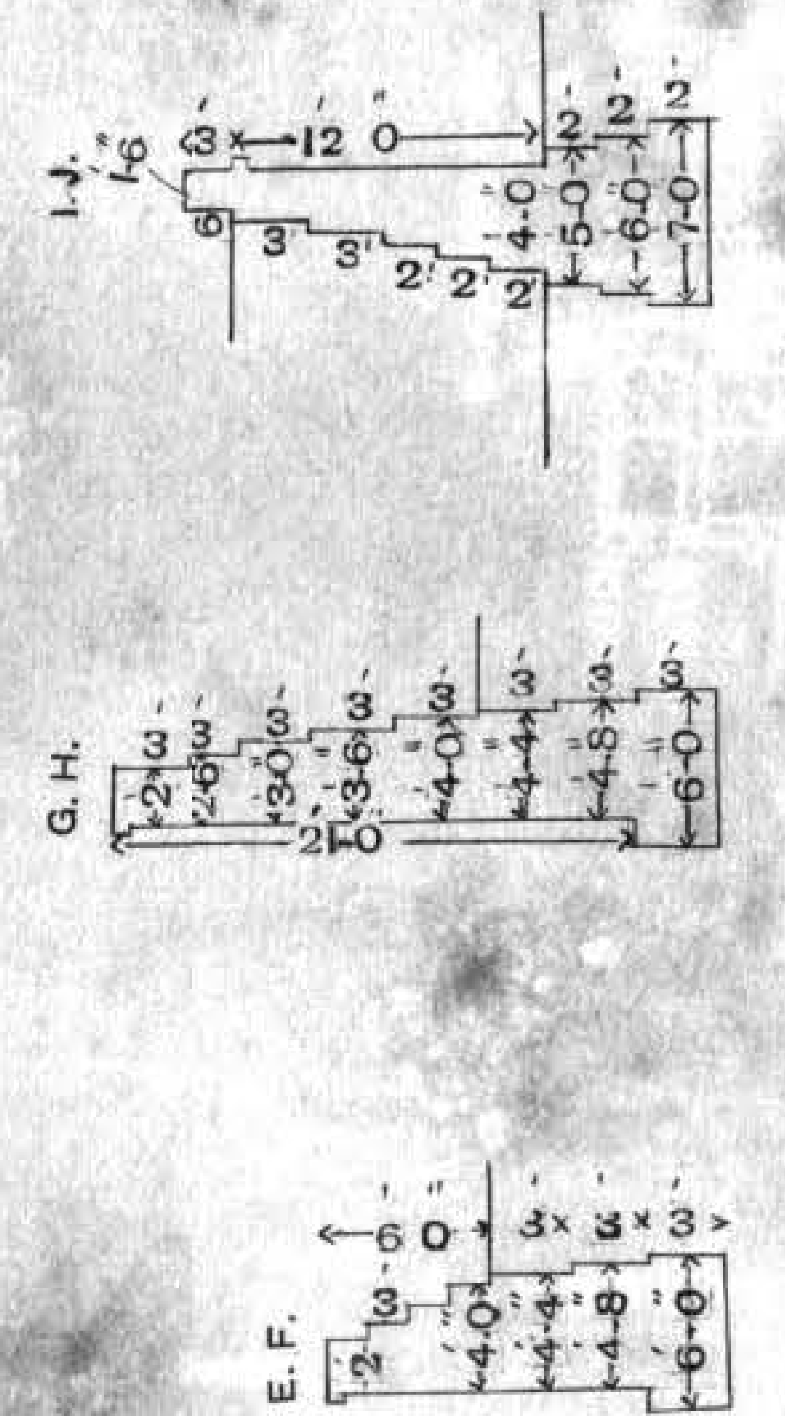
SECTION ON C.D



REAR ELEVATIN



SECTIONS ON



REFERENCE

Soil	Gravel
Sub Soil	Kunkur Shale
Amount of Estimate Rs.	6850

- ▨ Arch Stones
- ▨ Cut Stone Work
- ☐ Course Rubble Work
- ▤ Rough Stone in Mortar
- ▥ Do. Packing & Apron
- ▦ Concrete Broken Stone in Mortar

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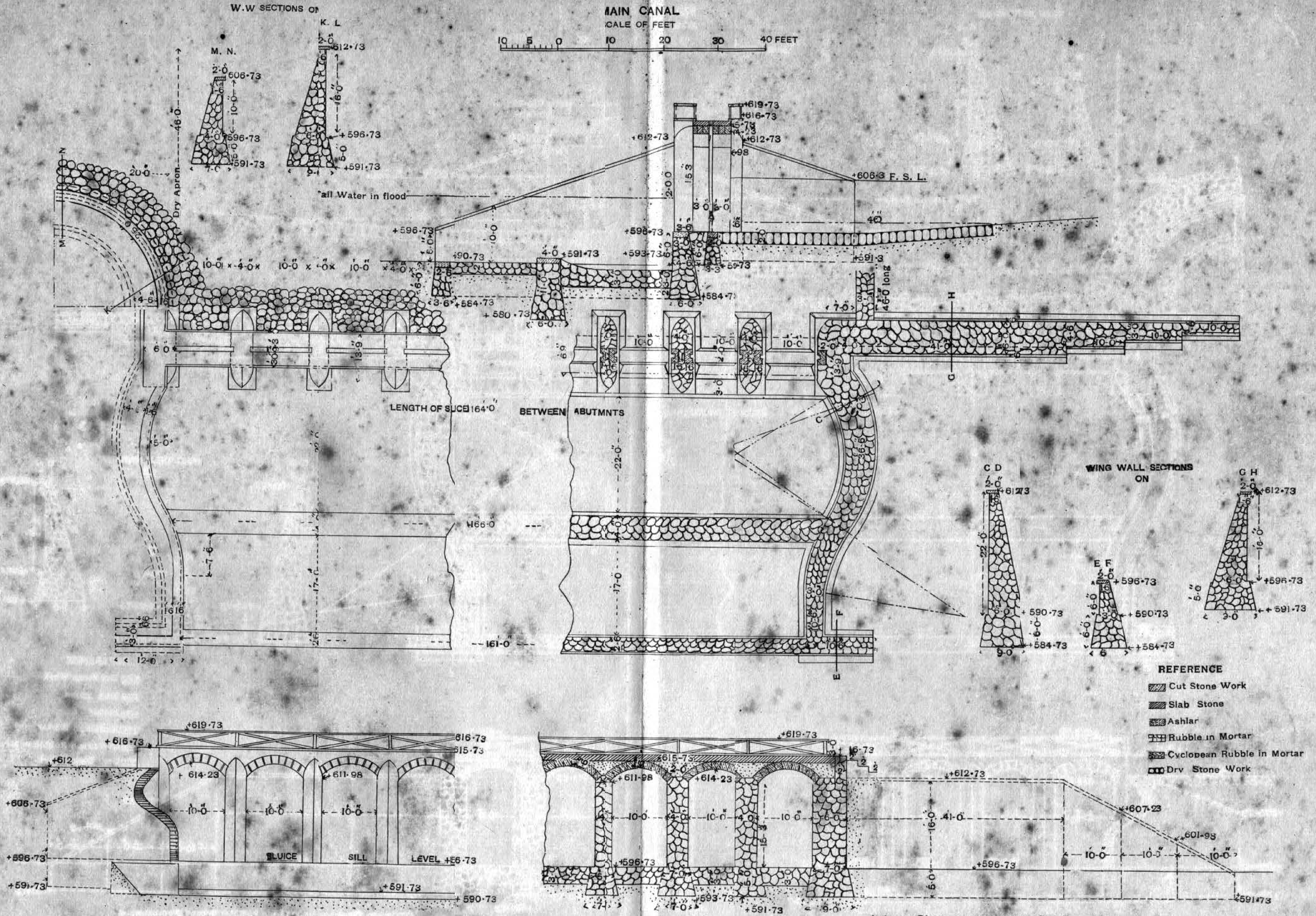
PLAN OF A SURPLUS SLUICE OF 12 VENTS FOR R.MARAJAPURAM TANK

AT 3 MILES 7 FUR AND 2·72 CHAINS FIRST REACH MAIN CANAL

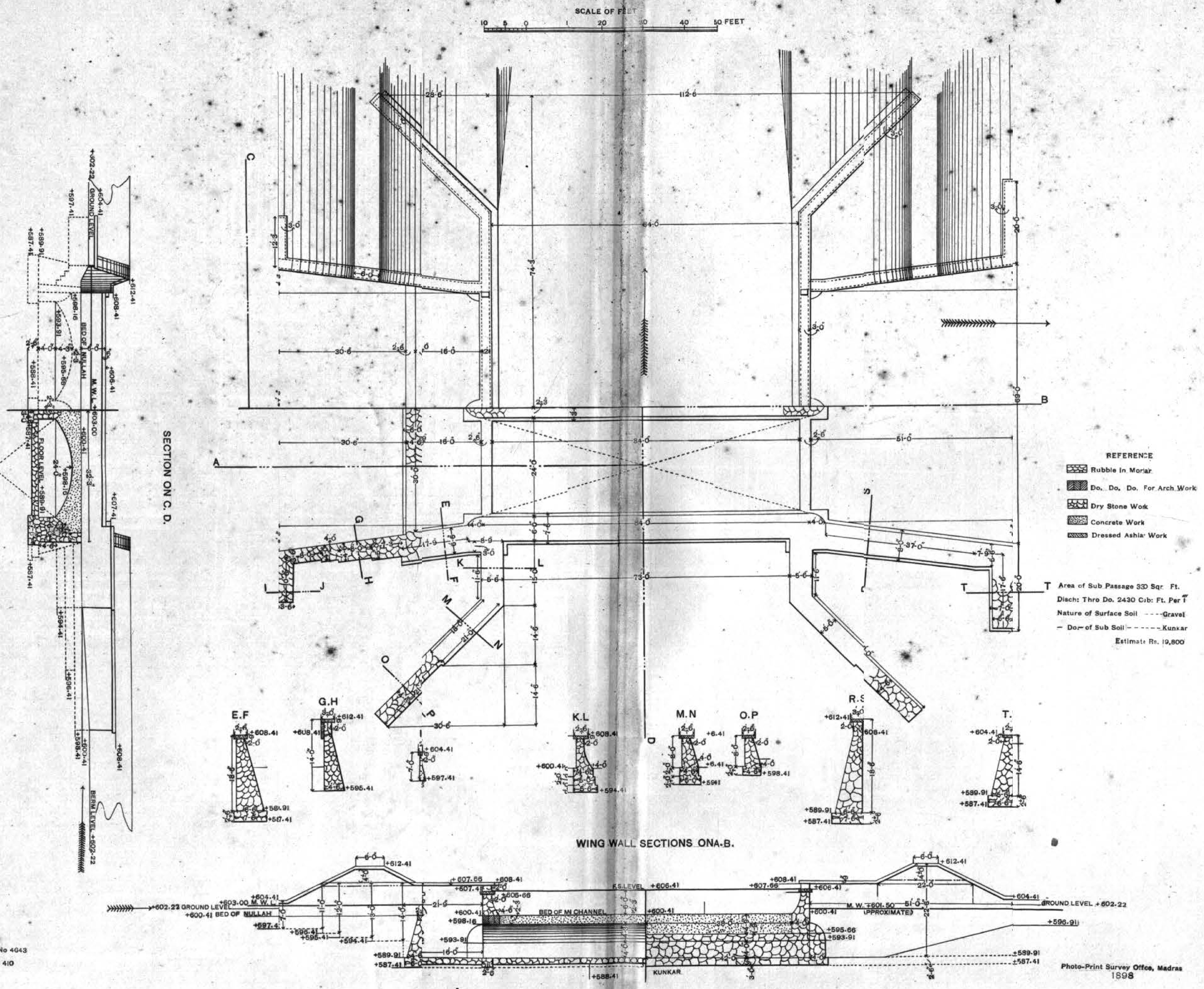


Maximum Discharge 11400 Cubic feet Per Second (Approximate)

Amount of Estimate Rs 32400

Reg: No. 4642

PLAN OF AN AQUEDUCT OF TWO VENTS AT 10TH MILE IN 2ND REACH
OF
NORTH MAIN CHANNEL



REFERENCE

- ▨ Rubble in Mortar
- ▨ Do. Do. Do. For Arch Work
- ▨ Dry Stone Work
- ▨ Concrete Work
- ▨ Dressed Ashlar Work

Area of Sub Passage 330 Sqr. Ft.
Disch: Thro Do. 2430 Cub: Ft. Per 1"
Nature of Surface Soil ----Gravel
— Do. of Sub Soil -------Kunkar
Estimate Rs. 19,800

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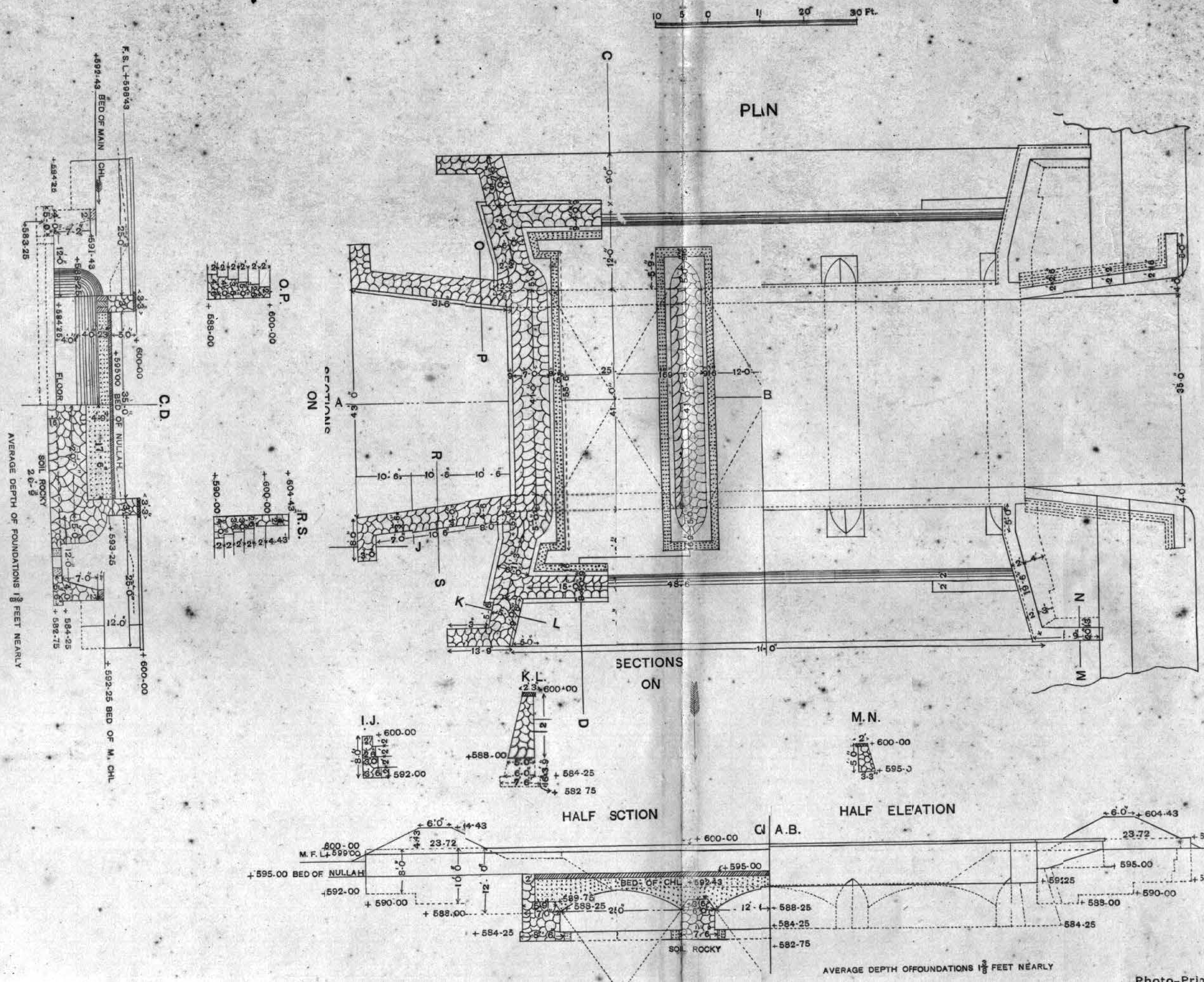
NO. 8 SUPERPASSAGE

AT 13 MILES 2 FURLONGS & 4·09 CHAINS,

3RD REACH MAIN CHANNEL.

PLATE NO. XIX



REFERENCE

- ▩ Coursed Rubble in Mortar
- ▧ Do, for Arch Work
- ▦ Concrete Work
- ▨ Slab Stones
- ▩ Dressed Ashlar
- ▥ Dry Stone Work
- ▩ Roughly dressed Ashlar

Surface soil ...., Hard gravel
Sub Soil............ Rock

Amount of Estimate Rs. 135.00
Drainage Area 5 Square Miles
Sub passage Area 504 Square feet
Disch: Thro: Do. 1608 Cub: Ft. Per 1"

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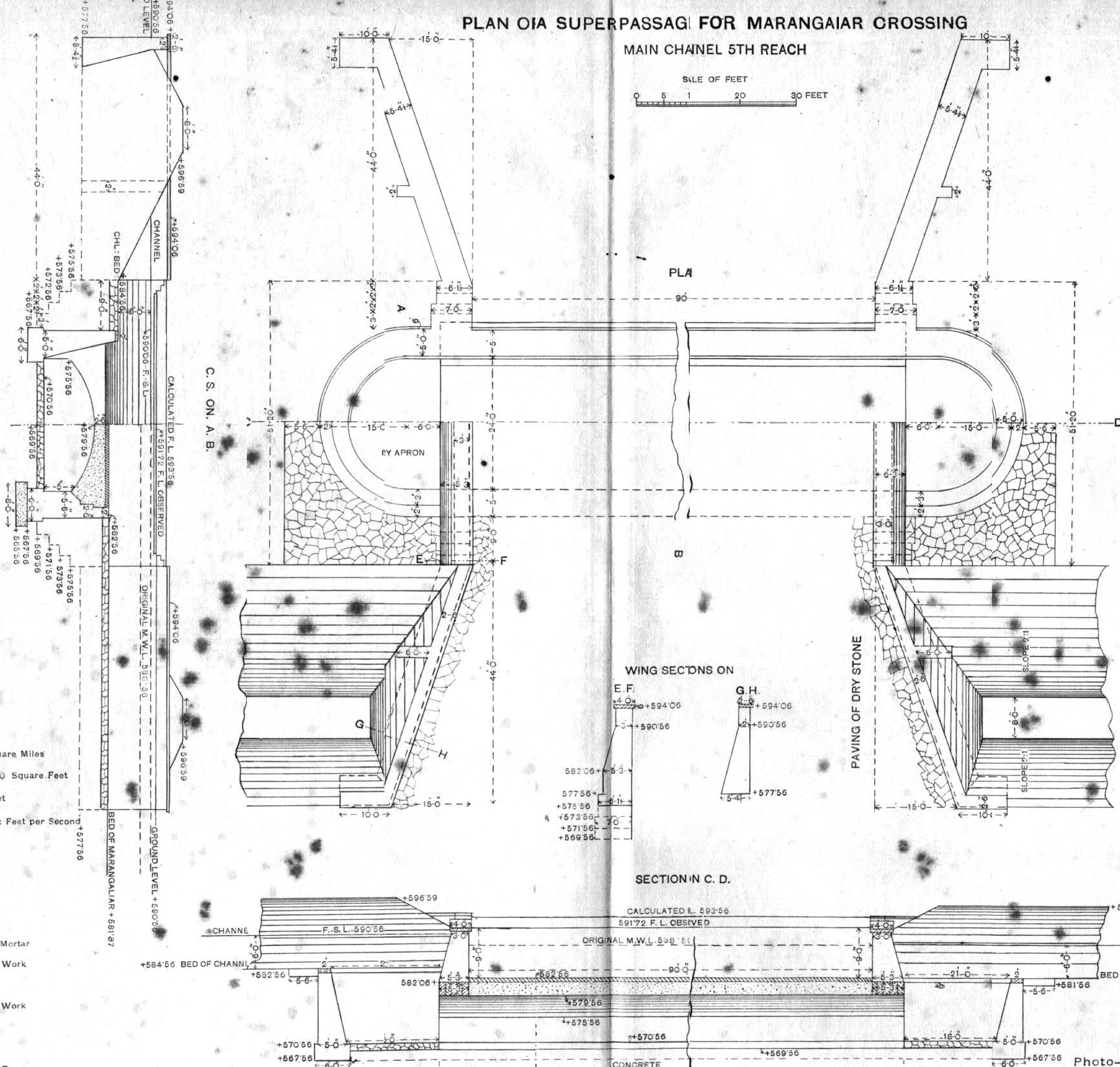
PLAN OF A SUPERPASSAGE FOR MARANGAIAR CROSSING

MAIN CHANNEL 5TH REACH



Drainage Area 62 Square Miles

Area of Waterway 810 Square Feet

Depth of Water 9 Feet

Discharge 10962 Cubic Feet per Second

REFERENCE

- ☐ Rubble in Mortar
- ▨ Cut Stone Work
- ▨ Slab
- ▦ Dry Stone Work
- ⬚ Concrete

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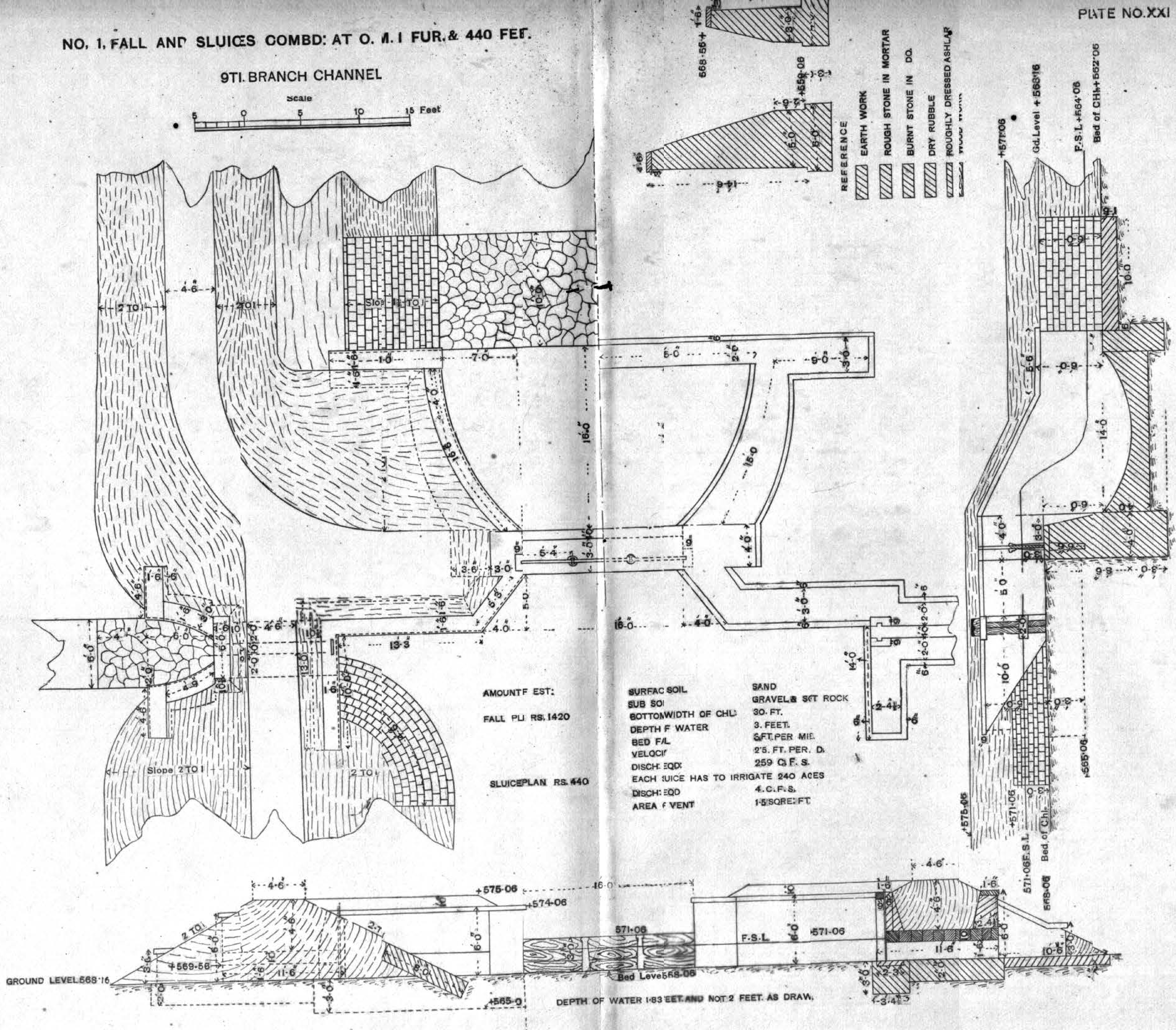
NO. 1. FALL AND SLUICES COMBD: AT O. M. 1 FUR. & 440 FEET.

9TH. BRANCH CHANNEL



AMOUNT OF EST:

FALL PLAN RS. 1420

SLUICE PLAN RS. 440

SURFACE SOIL	SAND
SUB SOIL	GRAVEL & SOFT ROCK
BOTTOM WIDTH OF CHL:	30. FT.
DEPTH OF WATER	3. FEET.
BED FALL	5 FT. PER MILE
VELOCITY	2·5. FT. PER. D.
DISCH: REQD:	259 C. F. S.
EACH SLUICE HAS TO IRRIGATE 240 ACRES	
DISCH: REQD	4. C. F. S.
AREA OF VENT	1·5 SQRE: FT

DEPTH OF WATER 1·83 FEET AND NOT 2 FEET AS DRAWN.

PLATE NO. XXII

DROP NO.

II THE 12TH BRANCH CHANNEL

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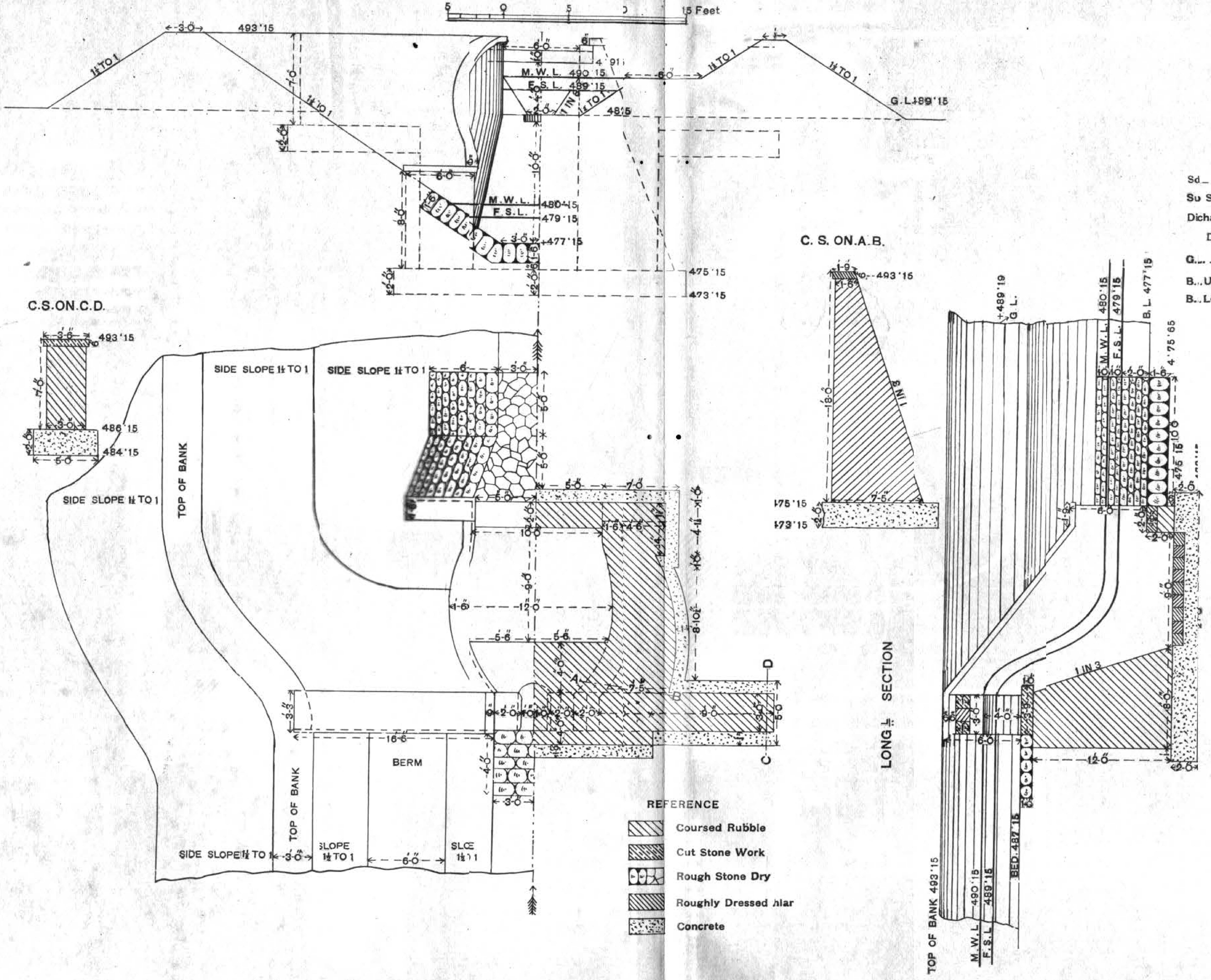
XIth BRANCH CHANEL

FALL OF 10 FEET



REFERENCE

▧ Coursed Rubble
▨ Cut Stone Work
▦ Rough Stone Dry
▨ Roughly Dressed Ashlar
▩ Concrete

REFERENCE

Sd — — — — — — Earth
Su Soil — — — — — Gravel
Dicharge M. W. L. — — 61. C. F S.
Do. F. S. L. — — 28·00
G.. — — — — — — 489·19
B.. Upper — — — — — 487·15
B.. Lower — — — — — 477·15

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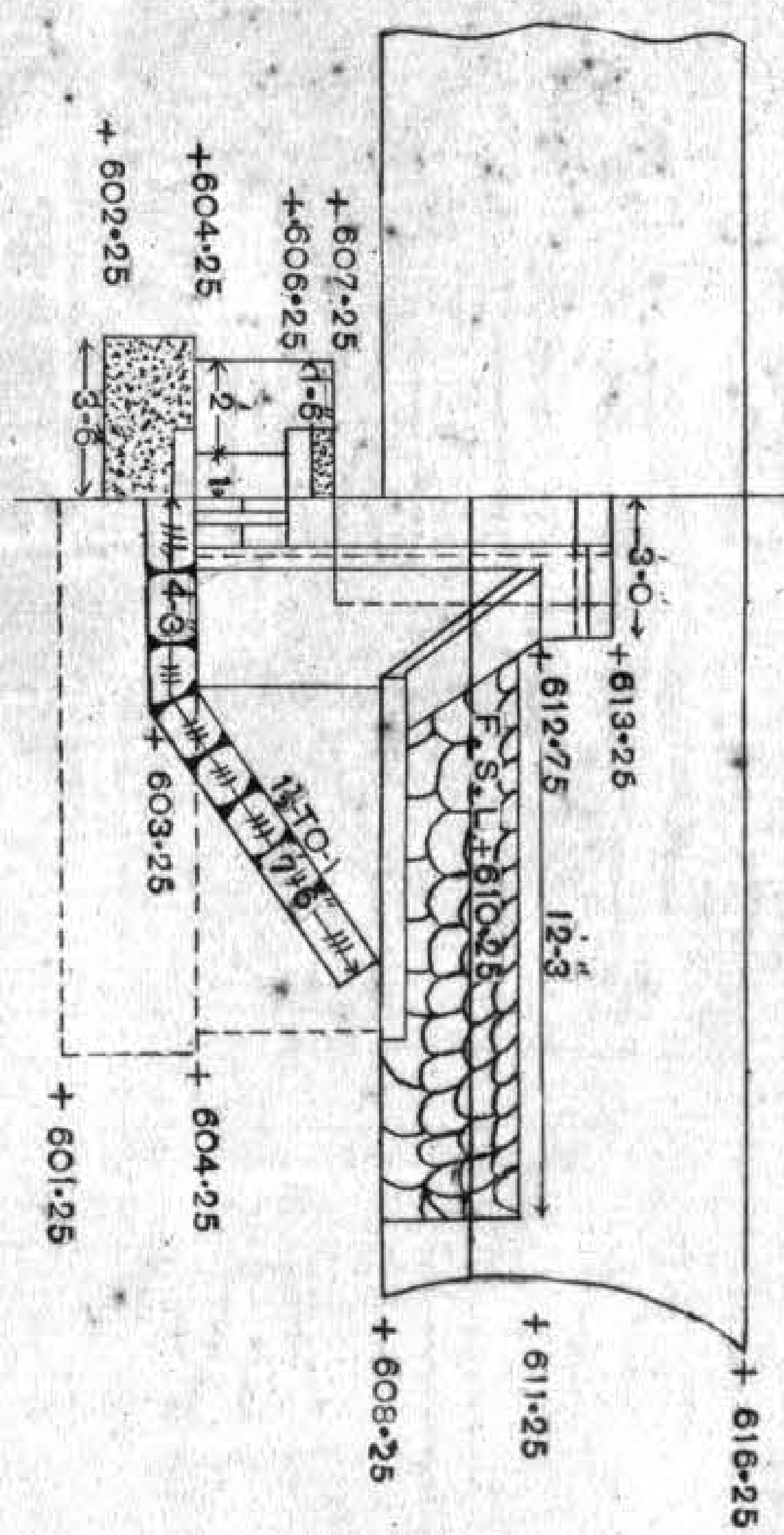
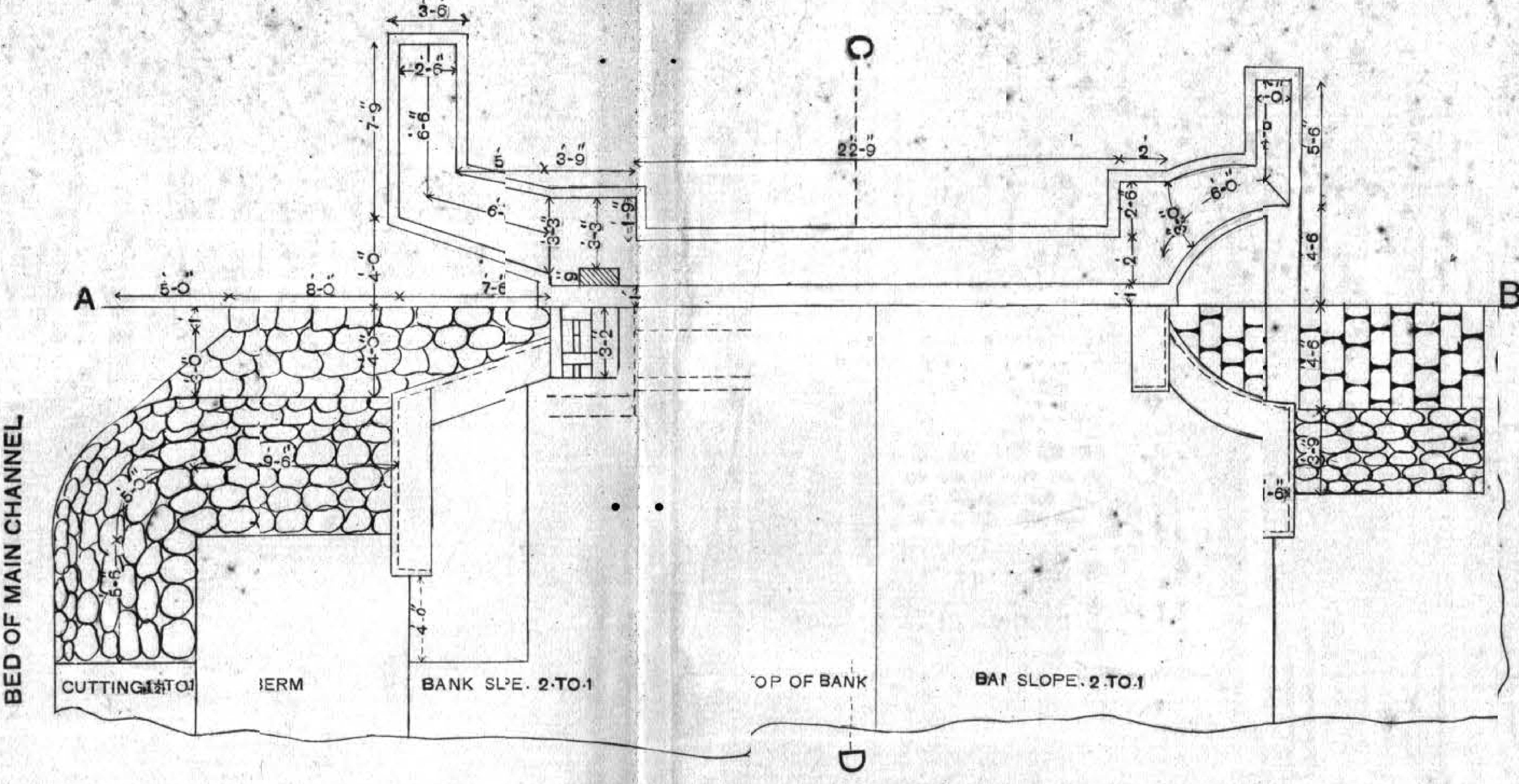
IRRIATION SLUICE, AT 5 MILES.4 FUR
IN THE FIRST REACI MAIN CHANNL.

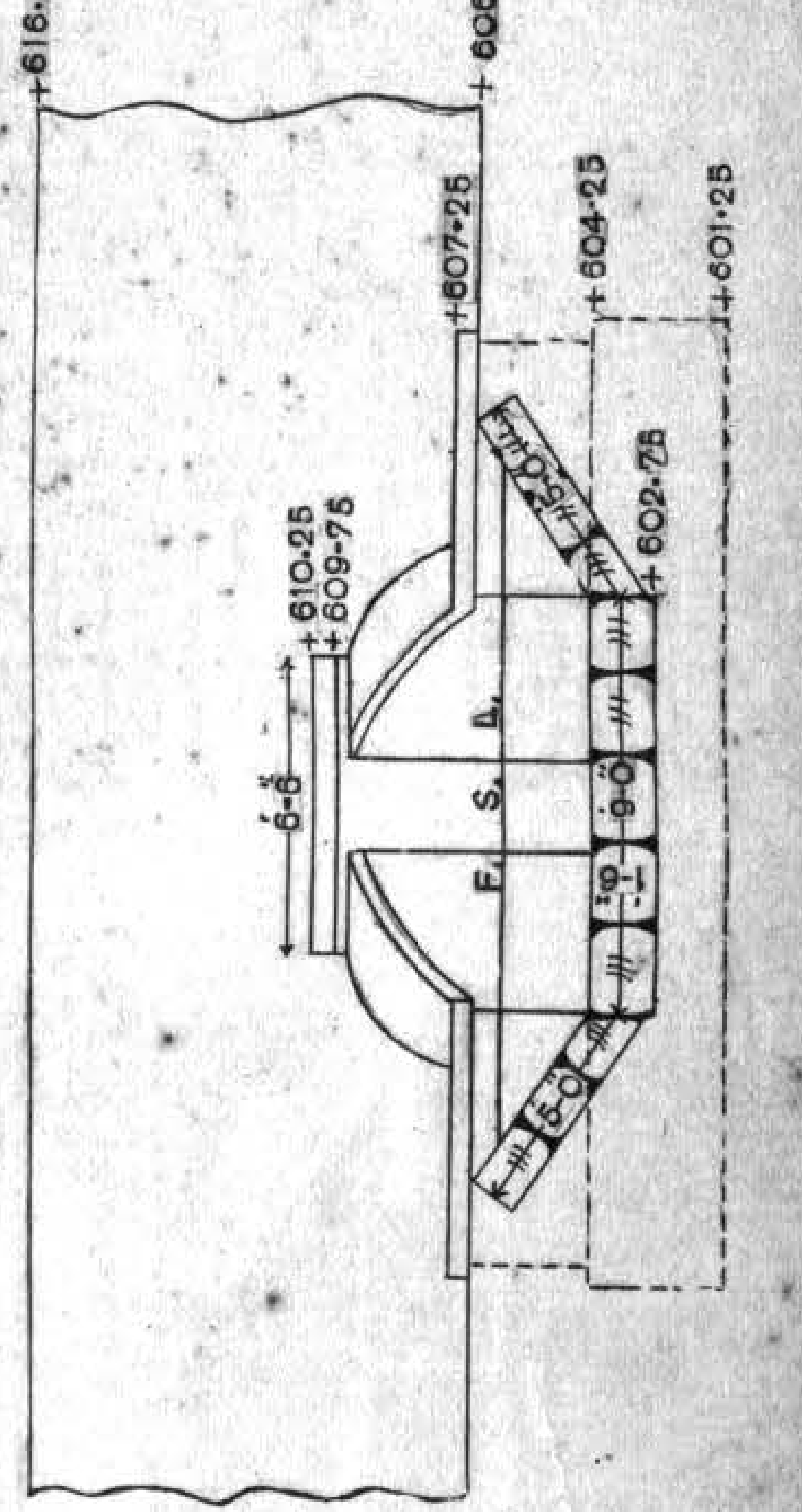
Sca

5 0 5 10 15 20 25 FEET



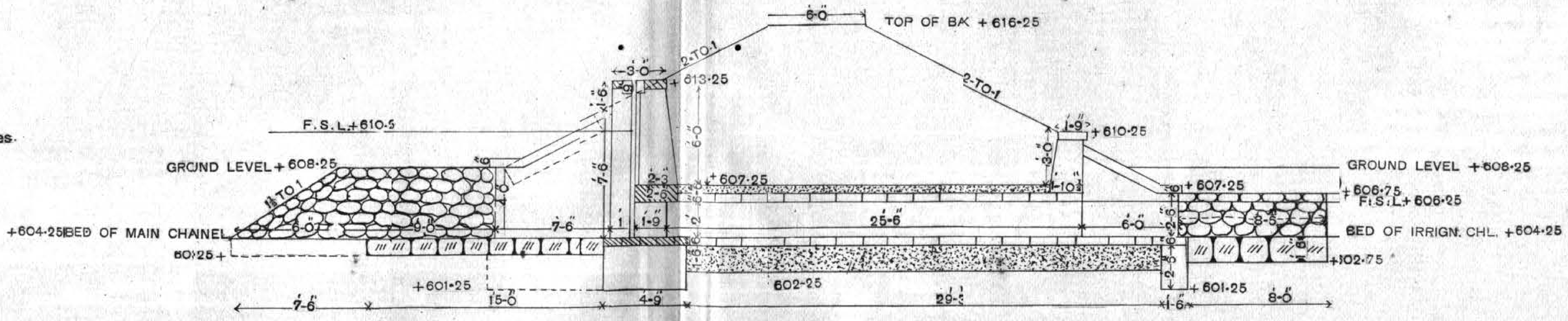
SECTION ON C. D.





REAR ELEVATION

LONGITUDINAL SECTION ON A..



REFERENCE

- ▭ Burnt Stone in Mortar
- ▨ Cut Stone work
- ▒ Slab Stone work
- ▢ Dry Rubble
- ▩ Concrete

Depth of water in front 6'
Do. At Rear 2'
Area to be irrigated 200 Acres.
Estimate Rs. 700

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PLATE NO. XXV

IRON TROGH

REFERENCE.

▦	Burnt Stone in Mortar
▤	Roughly Dressed Ashlar
▧	Slab Stone Work
▩	Concrete work
☐	Iron work

Soil	gravel
Sub Soil	hard Gravel
designed by	
Bottom Width of Chl.	51·20
Cutting	1½ to 1
Depth of water	6 Feet
Amount of the Est	Rs. 950

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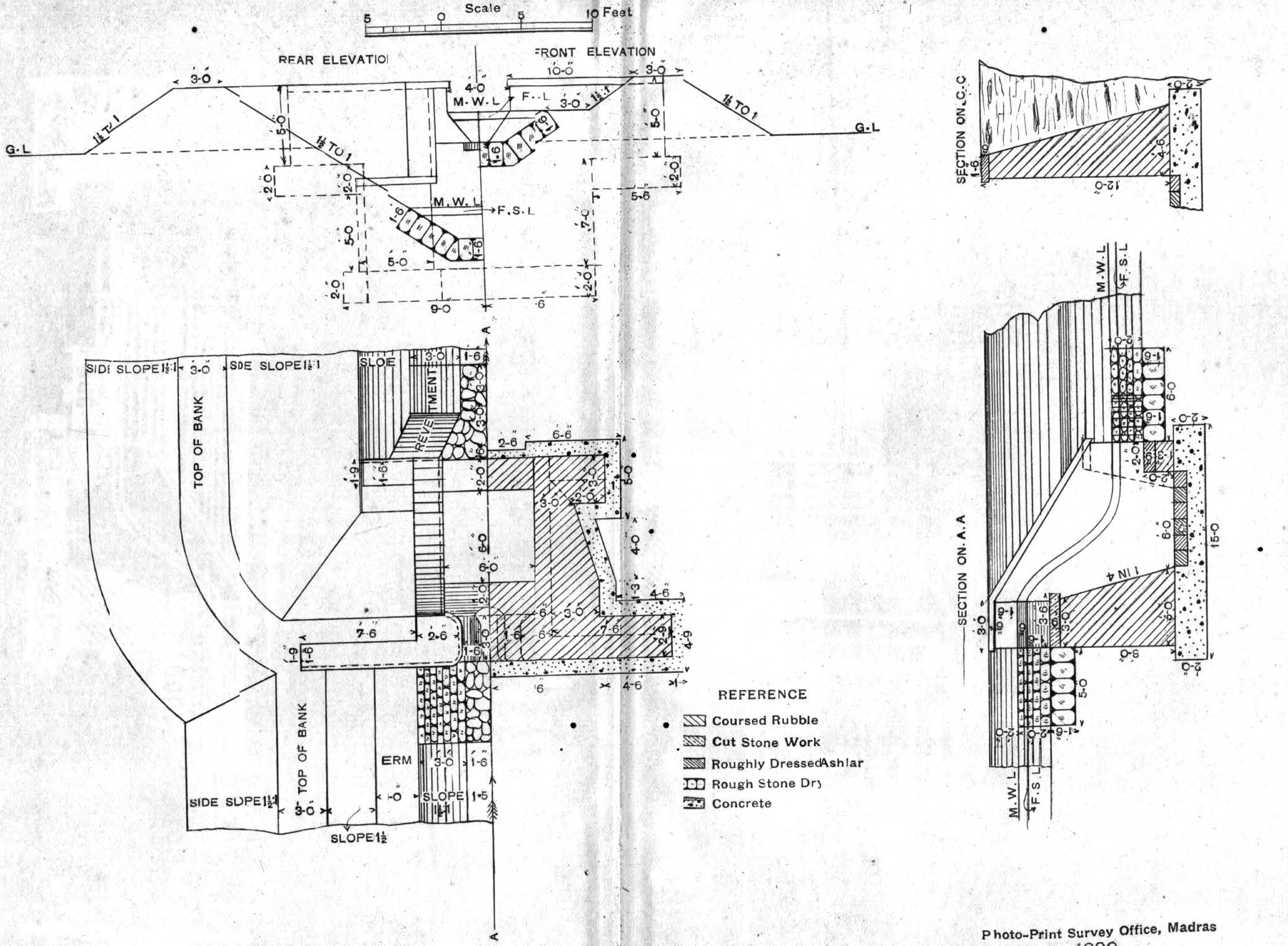
OF
6 FEET FALL



REFERENCE

- ▧ Coursed Rubble
- ▨ Cut Stone Work
- ▩ Roughly Dressed Ashlar
- ▢ Rough Stone Dry
- ▦ Concrete

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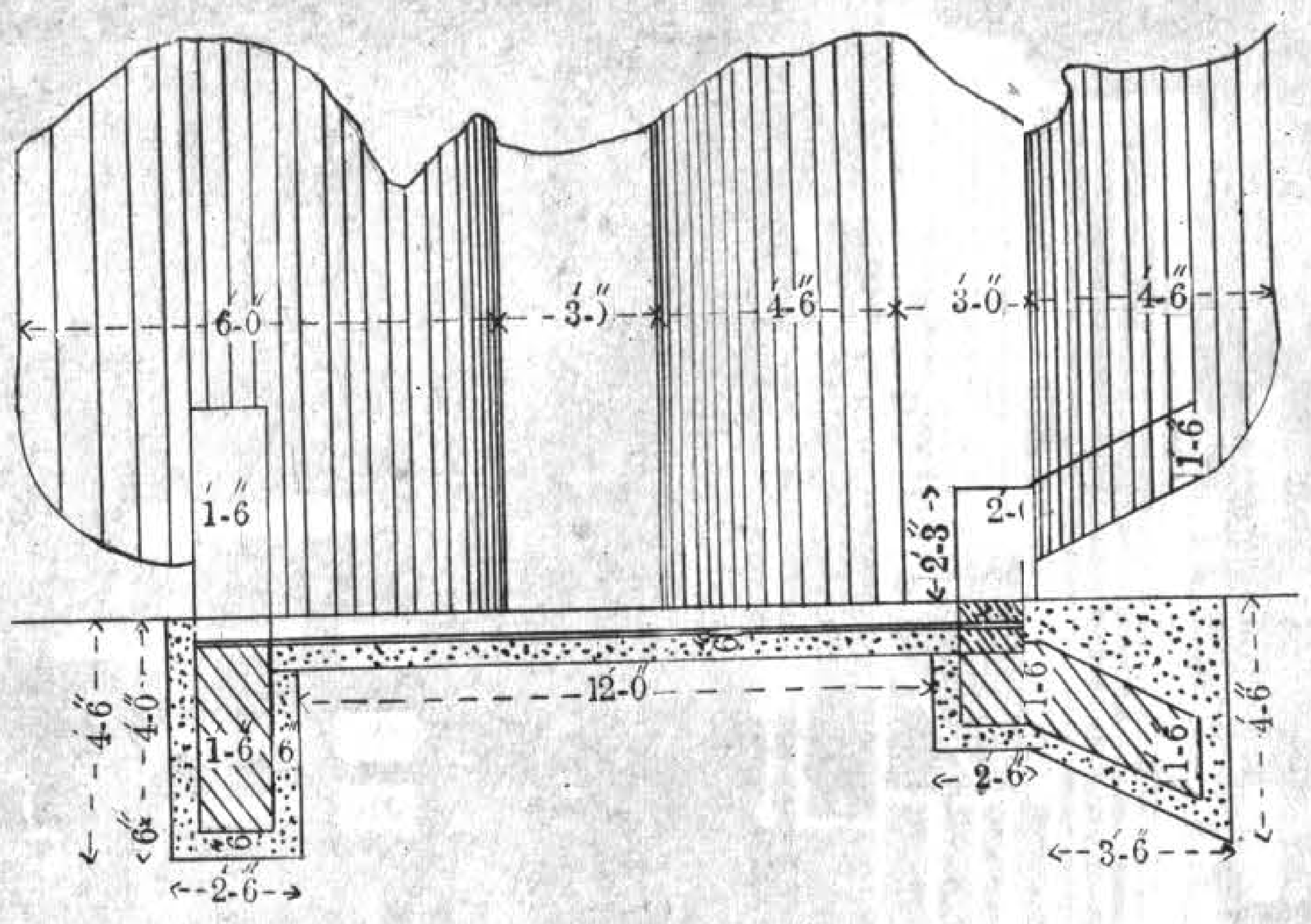
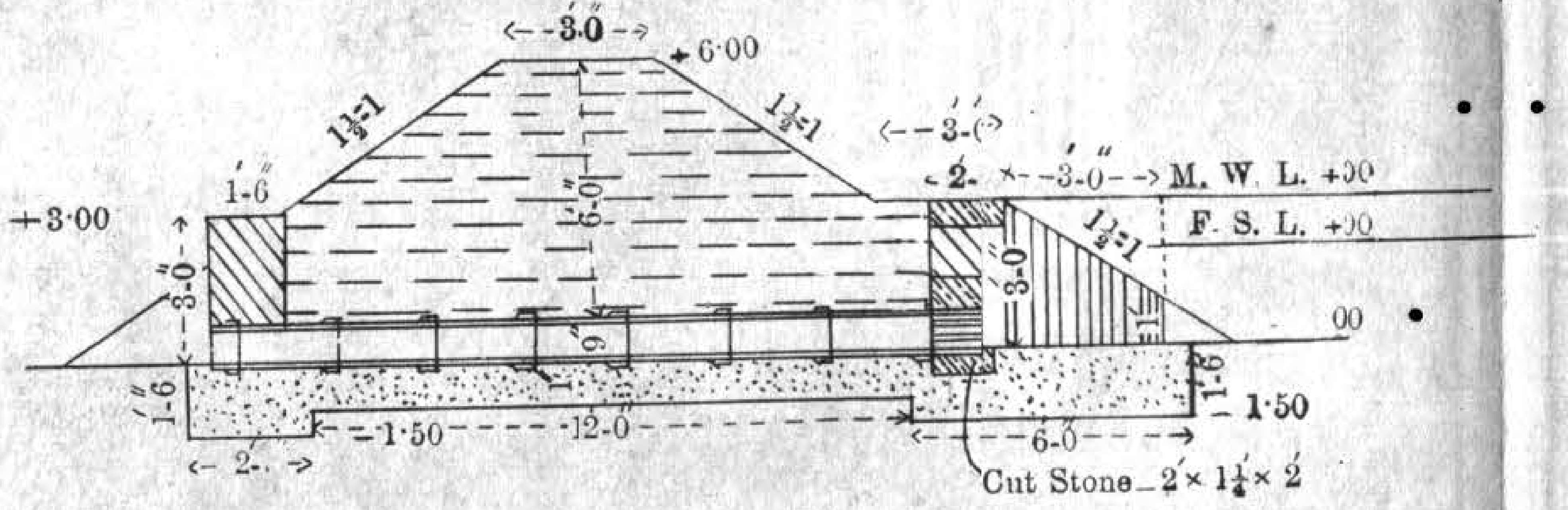
PLATE NO. XXVII

TYPE DESIGN
FOR
9" OR 12" DR. PIPE SLUICES

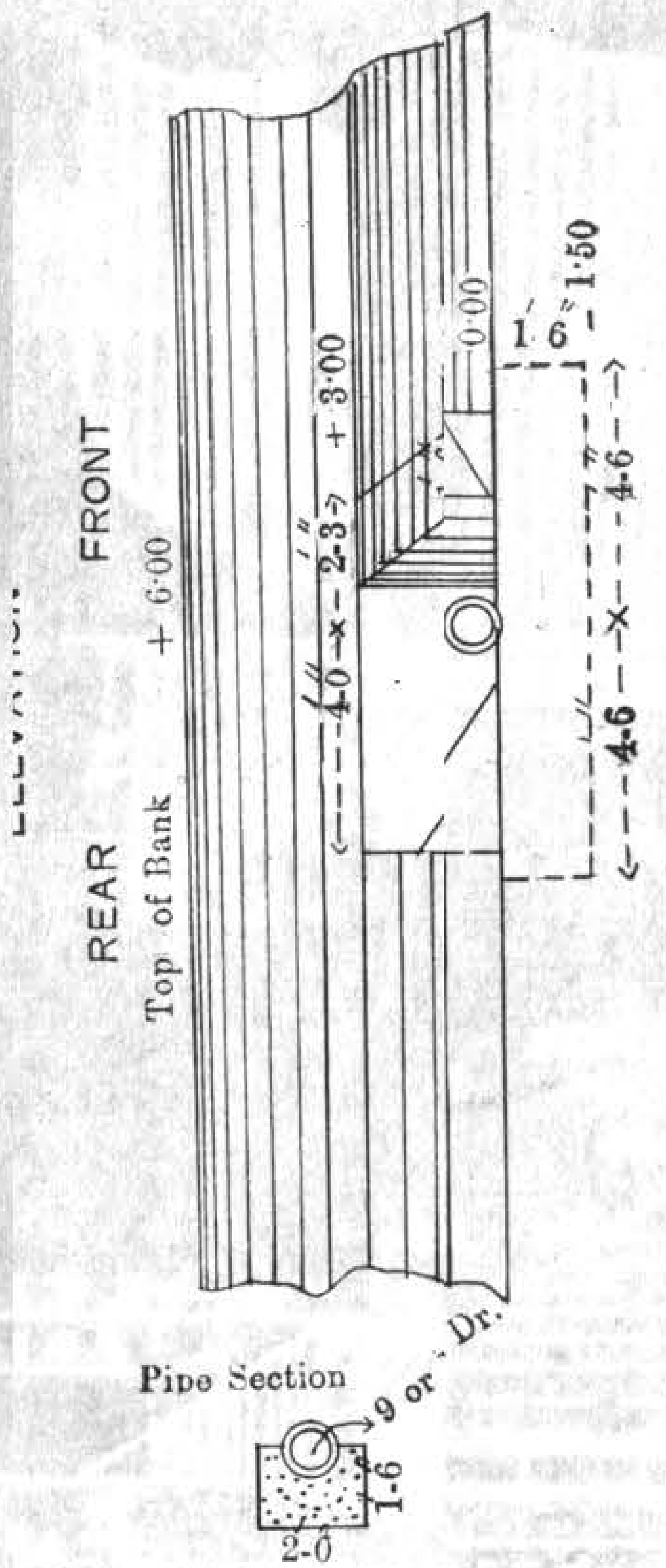
Scale
5 0 5 10 Feet



LONGITUDINAL SECTION



Cut Stone 2'× 1¼'× 2'



REFERENCE

▨ Coursed Rubble

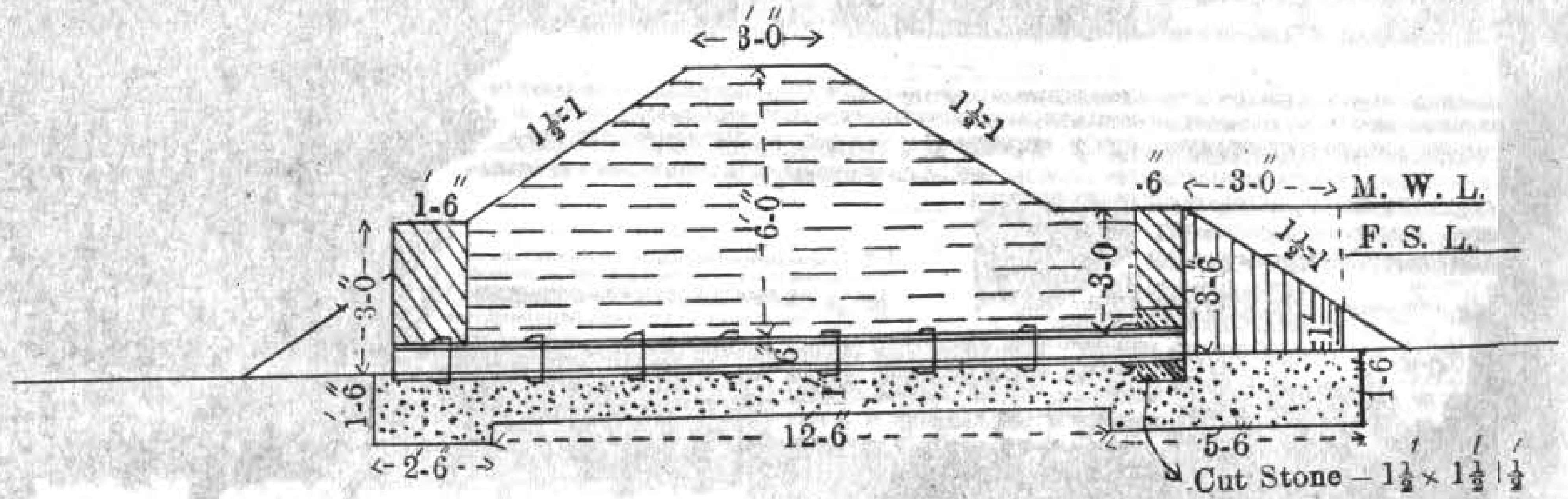
▨ Cut Stone

░ Concrete

TYPE DESIGN
FOR
6" DR. PIPE SLUICES

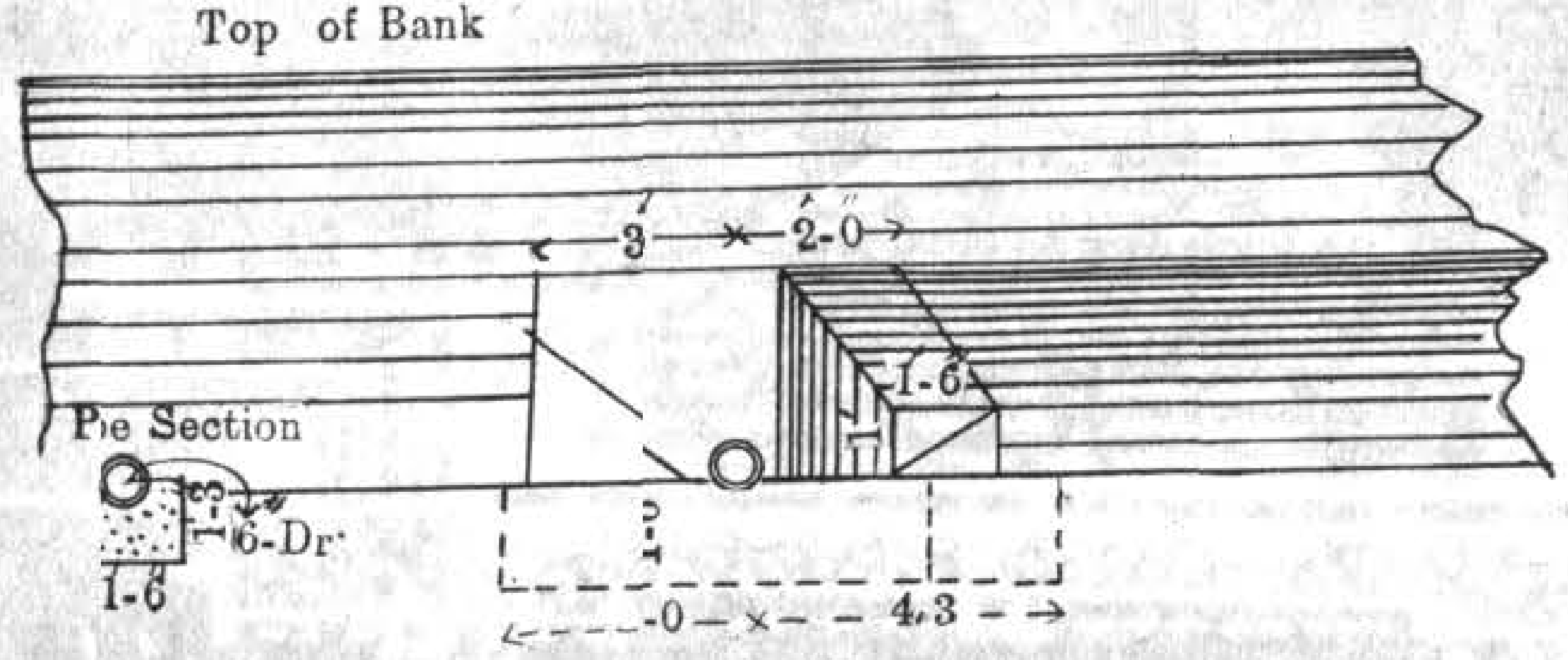
Scale
5 0 5 10 Feet

LONGITUDINAL SECTION



Cut Stone – 1½'× 1½'× 1½'

ELEVATION



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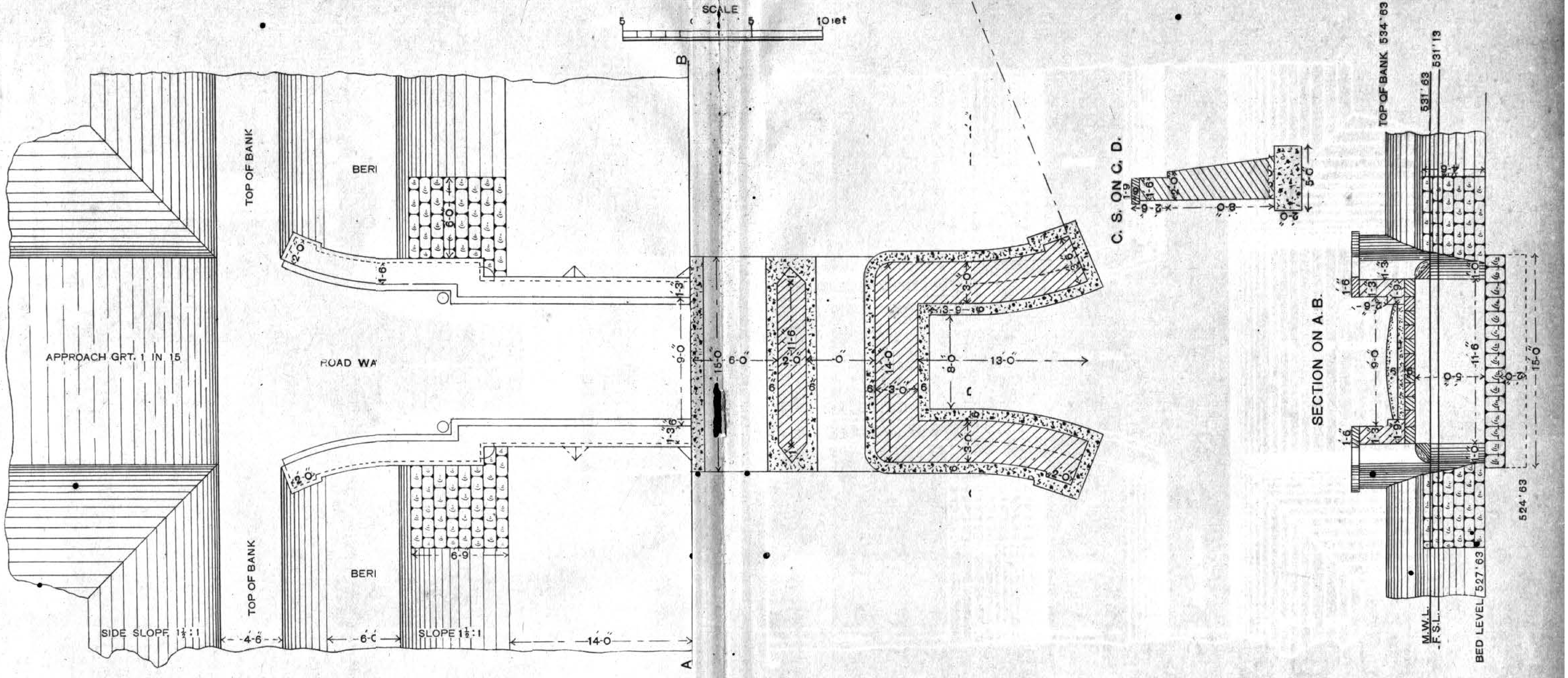
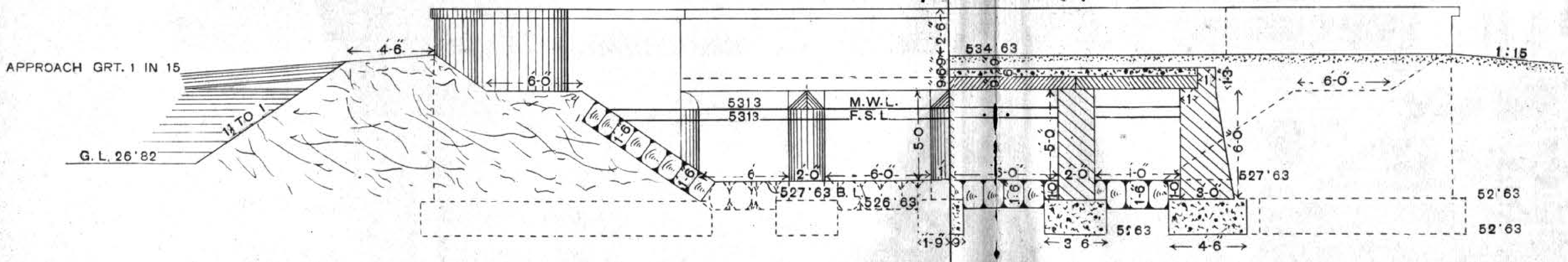
A BRIDGE
IN THE XIIBRANCH CHANNEL.

SCALE



HALF ELEVATION. HALF LONGL. SECTION



REFERENCE

Soil.........Earth
Sub Soil...At 2½' Gravel
Estimate Rs.1020

▨ Coursed Rubble
▨ Roughly Dressed Ashlar
▨ Rough Stone Dry
▨ Concrete
▨ Road Metal

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